A Transdisciplinary Implementation of Sustainable Agricultural Principles in the Waikato Region of New Zealand

Hendrik van Zyl

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Main supervisor: Dr J.H.S. Roodt

Co-supervisor: Dr D.A. Care

Faculty: Centre for Transdisciplinary Research and Innovation

15 August 2019

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Declaration

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Hendrik van Zyl 15 August 2019

Abstract

The Primary Industry in New Zealand (NZ) generated $42 billion in export revenue and employed over 350,000 people in 2018. It is central to the national identity formation in the country but is implicated in some of our most contentious environmental issues as well as raising new and challenging issues around rural/urban tensions, environmental stewardship, and the varying economic prosperity of agricultural businesses and rural communities.

The Ministry of Primary Industries prioritised “increased sustainable resource use” as a critical success factor to ensure the wellbeing of all New Zealanders. The challenge for a commercial vegetable farming operation is how to embed sustainable agricultural principles in their operations to ensure a thriving, financially sustainable business. This research aimed to explore the link between human wellbeing, plant health and soil health while maintaining profitability and business resilience.

The study focused on the Matamata operations of A.S. Wilcox and Sons Limited (ASW) in the Waikato region of New Zealand. Various stakeholders were involved in the co-creation process. The study used transdisciplinary and participative approaches to bring together qualitative and quantitative methods.

Interviews yielded information that could be used for strategic direction setting. Trials of change of practice of onion farming were run to understand how sustainable fertilising techniques and compost applications would impact plant health, soil health, yield, quality and profitability.

The research has identified the need and demonstrated the potential benefits of embarking on a sustainability road for ASW. Key findings of this research project were that sustainability is demanded by the community at large and it is required by the customers of ASW. Eco-agricultural principles were successfully embedded in the business. The focus on fertigation and soil health amendments led to an increase of 27 t/ha in onion yield.

The organisation embarked on the strategic journey by establishing a new position to manage sustainable practices and innovation.

Keywords: Transdisciplinary Research, Fertigation, Compost, Sustainability, Innovation, Onions, Waikato, New Zealand.

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I also want to thank ASW for allowing me to conduct this research project while in their employ. Special thanks to Brent Wilcox, Director, and General Manager Growing, for supporting me during this project, My brother Herman for his professional, emotional, and academic advice.

Lastly, but most importantly, I want to thank my family for their support and enduring hard times during my absence from their daily lives. My father and mother for a lifetime's support. My wife Annemarie has been the voice of reason, the motivator, and the inspiration for this effort. Thank you for believing in me.

Contents

List of Acronyms and Abbreviations

AH	Allister Holmes
AIS	Agricultural Innovation System
ANOVA	Analysis of Variance
ASW	A.S. Wilcox and Sons Limited
AT	Amy Taylor
BSC	Balanced Score Card
Ca	Calcium
CEC	Cation Exchange Capacity
CEO	Chief Executive Officer
CFO	Chief Financial Officer
CTF	Controlled Traffic
EA	Eco-Agriculture
EM	Effective Micro-organisms
ETo	Evapo-Transpiration
EU	European Union
FAR	Foundation for Arable Research
Fe	Iron
FOA	Food and Agriculture Organization of the United Nations
GIS	Geographic Information System
GLOBALG.A.P.	Global Good Agricultural Practices
GMO	Genetically Modified Organisms
GRASP	GLOBALG.A.P. Risk Assessment on Social Practice
HILL	Hill Laboratories Limited
HR	Human Resources
IPM	Integrated Pest Management
JA	John Austin
K	Potassium
KB	Kelvin Bezuidenhout

KPI	Key Performance Indicator
Mg	Magnesium
MP	Member of Parliament
MPI	Ministry for Primary Industries
MRL	Maximum Residue Levels
N	Nitrogen
NIWA	National Institute of Water and Atmospheric Research
NRCS	National Resource Conservation Service.
NZ	New Zealand
P	Phosphorus
PEST	Physical, Economic, Social and Technological
PM	Production Manager
QC	Quality Control
S	Sulphur
SDG	Sustainable Development Goals
SEDEX	Supplier Ethical Data Exchange
SFINZ	Soil Foodweb Institute New Zealand
SSM	Soft Systems Methodology
SWOT	Strengths, Weaknesses, Opportunities and Threats
TDR	Trans-Disciplinary Research
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
UN	United Nations
US	United States of America
WINTEC	Waikato Institute of Technology
Zn	Zinc

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Chapter 1: Introduction

1.1 Background and Motivation

In 2003, Bertie van Zyl, founder of the researcher's family's business ZZ2®, was diagnosed with prostate cancer and passed away in 2005. His death was devastating to the family, and to the business, Bertie was a leader in the agricultural industry in South Africa and internationally (ZZ2, 2019). Not long afterwards, two of his brothers, including the researcher's father, were also diagnosed with prostate cancer. The question arose why did these tomato farmers fall prey to a disease that is annually infecting 238 590 lives in the United States alone? (Siegel, Naishadham, & Jemal, 2013).

The Van Zyl brothers had been farming for most of their lives, and they lived in harmony with nature. The researcher's father knows every tree and every endemic plant in the region by name. They were active, hardworking, and lived relatively healthy lives. Was the disease passed down genetically, or was it caused by environmental factors associated with the industry they were involved in? Tomato farming in South Africa in the '50s, the 60s, and 70s were known for harsh chemical product use, and health and safety was not a priority. These questions set the researcher on a path to discover whether a thriving future is linked to the connection between human health, plant health and soil health.

The researcher was a commercial vegetable farmer, working with A.S. Wilcox and Sons Ltd (ASW) in the Waikato region of New Zealand at the start of this research project. His son is the 12th generation of his family farming with vegetables, and he would like his children and their children to continue this legacy.

How do we as commercial vegetable farmers in the Waikato, implement the necessary change to not only continue what we are doing currently but also to become a thriving business in future?

The first thoughts were focused on specific single discipline approaches: could yield and quality be increased by alternative irrigation techniques? A research project was launched on the premises of ASW in Matamata to investigate the efficacy of drip tape irrigation (Not part of this master's study). The results indicated that significant yield gains and a reduction in nitrogen applications were possible in onion production under this regime. However, it lacked the broader scope of the real-world problem. How to manage the environmental, social, financial and regulatory factors associated with Eco-Agriculture, could not be addressed by drip irrigation alone.

Following these results, a fact-finding mission to Australia's major onion producers led to the belief that it was not the irrigation on itself that caused the most significant gains. It was believed that it was the combination of irrigation and fertilisers (fertigation) and the more efficient delivery of the fertigation to the root system of the plants that caused the higher yields and better quality.

On my return to New Zealand (NZ), another research project was initiated to explore this, and the results showed improvements in yield and quality, as far as size profiles and skin set goes. It was clear though, that there was a much bigger issue that could not be solved by addressing fertigation as a single intervention in a more complex production system that also had to address societal and regulatory needs. For example, consideration must be given to suppliers, policy and planning functions, landowners and the ASW workforce and the future of their families, etc.

If there is a link between human wellbeing, plant health and soil health in general, then it would be in the interest of all farmers to consider their farming practices as part of their business strategy, with a focus on the health of the soil and the plants. Further to this, society is starting to expect farmers to take responsibility in this regard and to look after the environment as well (Méndez, Bacon, Cohen, & Gliessman, 2015).

Mendez *et al*. (2015) are of the opinion that we are dealing with a complexity that requires a holistic approach. The complexity of agriculture on its own merits the investigation of a more complex methodology in discovering the answer to this larger question (Campbell, 2009). Agriculturists in the modern world are integrators of multiple disciplines ranging from finances, human resources, law, marketing, engineering, horticulture, climatology, environmentalists and many more (Merrill, 1983). There is thus agreement that a transdisciplinary approach to addressing the problem as described above, is required (Méndez et al., 2015, p. 5).

This research project aims to investigate and explore options that could potentially support the implementation of Sustainable Agricultural Principles in the Waikato Region of New Zealand and to eventually implement change in a commercial vegetable farming operation to embrace soil health, plant health, and societal concerns that will make a difference to the real-world problem of establishing harmony between the land, the fauna and flora and the people farming on it.

Transdisciplinary research (TDR) approaches will be followed to bring about integrated, innovative and socially acceptable outcomes. ASW will be used as a case study to investigate these options as the researcher is in their employ.

1.2 Problem Statement

The Primary Industry in NZ generated $42 billion in export revenue and employed over 350,000 people in 2018 (Ministry for Primary Industry, 2019). It is central to the national identity formation in the country but is implicated in some of our most contentious environmental issues as well as raising new and challenging issues around rural/urban tensions, environmental stewardship, and the varying economic prosperity of agricultural businesses and rural communities (Waikato Regional Council, 2018).

A growing consensus amongst customers, legislators, environmentalists, and farmers, exists for the implementation of a more sustainable, healthier food production approach. According to Higa and Parr (1994), "*chemical-based, conventional systems have created many sources of pollution directly or indirectly and contribute to the degradation of the environment and destruction to our natural resources*" Agricultural systems which follow the principles of natural ecosystems are receiving considerable attention in both developed and developing countries.

Policy and regulatory changes are demanding increasing changes from farming communities; this creates a level of distrust between the state, rural society, and the farming community (Renting & Van Der Ploeg, 2001). In the Waikato region of NZ and especially in the catchment areas of the Waikato and Waipa rivers, pressure on policy and regulatory changes are mounting (Waikato Regional Council, 2018).

The problem can be summarized by asking how might we embed sustainable agricultural principles in a Waikato based, commercial vegetable farming operation, in such a way that it will ensure a thriving business for the future?

What are the implications for ASW? A.S. Wilcox and Sons Ltd is an agricultural company with a long-term strategy. An overview of the company will be provided to the reader in Chapter 2.2.1. Being sustainable in what they do, and continuous improvement throughout the business forms part of their value proposition. As part of their purpose statement "*to grow healthy communities from the ground up by delivering goodness and value to their customers*", they are continuously looking at options to improve their sustainable production practises.

For ASW, a 'thriving business' means that they can be successful in achieving these goals while constantly innovating around their business models and on-farm practices. In this study, the on-farm practices and aspects of the strategy, informed by perceptions of their broad stakeholder base, will be addressed.

The researcher is also warned that many businesses have failed to successfully implement change due to a lack of focus (De Geus, 1997), and an inability to set boundaries for what is achievable within that particular business.

It is the opinion of the researcher that a change in farming practices is needed to secure sustainability. It is not clear how to do this in a way that will ensure long-term success, and to bring a thriving business into fruition.

There is an emerging agreement that sustainability challenges require new ways of knowledge production and decision-making. Lang et al. (2012) mention an essential aspect of sustainability namely: the involvement of actors from outside academia into the research process to integrate the best available knowledge, reconcile values and preferences, as well as create ownership for problems and solution options. "*Trans-disciplinary, community-based, interactive, or participatory research approaches are often suggested as appropriate means to meet both the requirements posed by real-world problems as well as the goals of sustainability science as a transformational scientific field*" (Lang et al., 2012).

A. Kuckertz *et al*. (2019), lists five steps of the food value chain.

1. "Agriculture: All activities and inputs required to cultivate crops and livestock".
2. "Transforming: Processing crops and livestock into food ingredients".
3. "Converting and Packaging: Composition of food products out of different ingredients and the transportation-ready packaging of the same".
4. "Shipping and Selling: Transportation, stocking and promotion of food to make it available for purchase".

5. “Consuming: Preparation of meals and provision of the same, e.g., in restaurants or at home”.

At the onset of this research project (Figure 1), the researcher was a member of the “Agriculture” (cultivation of crops – step 1 above), part of this value chain within the Growing team of ASW. The researcher, therefore, had to focus his efforts on that part of the business.

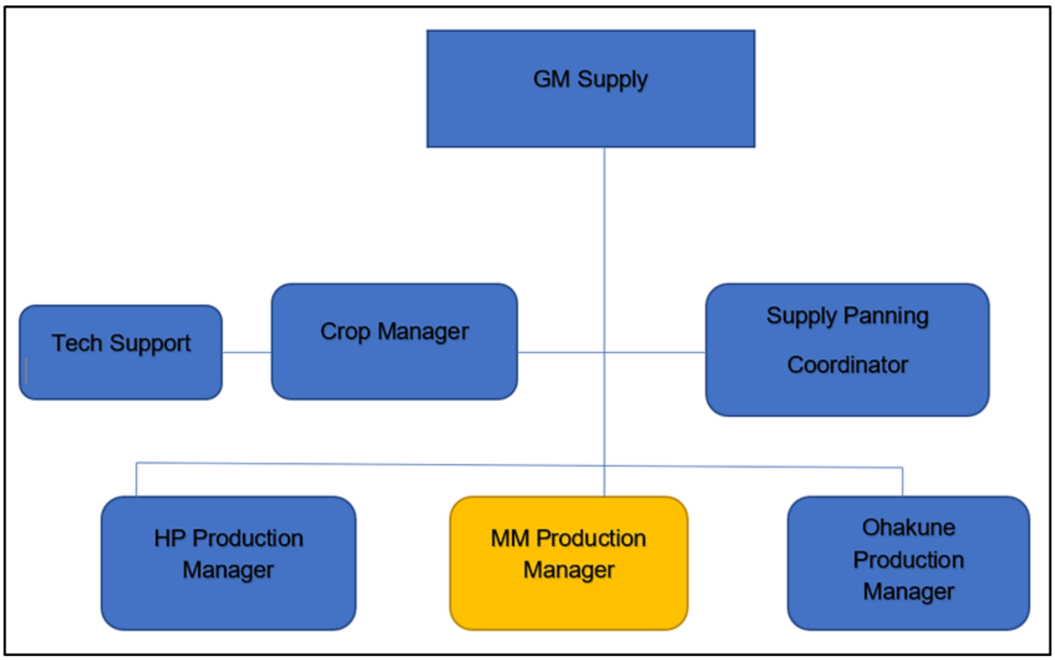

Figure 1: An organigram for the ASW supply team defining the researcher’s position in the supply (Growing) team from Jan 2016 to Jan 2019.

ASW is considered as an enterprise immersed in society, and the views of society must be included in bringing about change for ASW. This research project is a direct result of the collaboration between the Waikato Institute of Technology (Wintec) as the academic partner, ASW (industry partner) and the student (researcher).

1.3 Research Objectives

It is the assertion of the researcher that introducing appropriate ways of embedding sustainable agricultural production principles in a commercial vegetable farming operation will lead to a thriving enterprise, given that the business strategy and operational models are informed by the changing needs and perceptions of a diverse stakeholder group.

The objectives of this study are to discover through transdisciplinary research (TDR), how socially acceptable and sustainable production practices could be successfully implemented in a commercial vegetable farming operation in the Waikato, ensuring the commercial viability required for a thriving business. The main objectives are:

1. To determine through qualitative research in the form of an interview process with various stake holders, their perception of sustainability and relevant themes for strategic change towards a thriving commercial vegetable farming business.

2. By way of quantitative research, to investigate the potential for successful implementation of sustainable agricultural production practices in support of soil health and plant health improvements by evaluating if:
   a. Fertigation techniques and
   b. Compost applications are advantageous in comparison to a standard fertilizer programme in terms of yield, quality and financial results.

The research objectives must contribute to solving this real-world problem innovatively to have a positive effect on the People (Societal), Planet (Environmental) and Profit (Financial) aspects of sustainability (Palmer & Flanagan, 2016). Chapter 3 details the research design and methodology used in undertaking this research and the justification. Conclusions, recommendations and areas for further research were drawn up by induction and deduction of the findings from the two research objectives and reported in

Chapter 5. Recommendations were also based on observation and understanding of a sustainable farming approach.

1.4 Delineation and Limitations

This research project aimed to find solutions for real-world problems. It must be taken into consideration that ASW is a national business doing business in different geographical areas under different climatic conditions in New Zealand. Management styles of regional Production Managers and the complexity of climatic and local influences limited this study to the farming operation in Matamata.

This thesis did not attempt to address all the factors influencing sustainability but focused on what was practically implementable on the Matamata production unit in the timeframe allowed for the study.

A significant limitation of this research project was managing the variables associated with vegetable production in the geographical area described. Climatic condition, planting dates, varietal differences and soil type variations within the trial plots had significant impacts on the results. Vegetable crops are, to a great degree, effected in yield and quality by these factors.

Operational constraints limited the research scope to what was executable on a fully operational farming scale. Liquid fertilizers associated with fertigation systems worldwide were unavailable or too costly in NZ, and the researcher had to utilize what was available and what was cost-effective.

Although sustainability encompasses much more than what is covered in this research project (Geels, 2011) it was necessary to focus on where a real-world problem could be solved. Future studies and opportunities for the business will be elaborated on in Chapter 5.

There was a limitation on the researcher’s ability to replicate the treatments in the onion fertigation trial as this was conducted in a commercial planting of onions and the researcher had to consider the cost and the volume of work.

1.5 Underlying Assumptions

The accuracy and validity of the data are subject to the environment and the situation under which it is gathered. For example, for the scale of the study, it was assumed that the data collected from plot areas would reflect the overall performance of the crop in that area. The trial result could be affected by the local conditions.

The researcher had specific biases towards drip tape irrigation techniques at the start of the study. As the trials progressed and his insights changed, he re-formulated some procedures to fit with new understandings and the changing environment. This is reflected in Chapter 3 and Chapter 4. In the design of the qualitative research, the researcher used the framework from Ken Wilbur’s integral theory to inform his choices of participants (Wilbur, 1997). This way it was assured that a diverse set of viewpoints or realities, relevant to the business, would be covered.

1.6 Definition of Terms and Concepts

In this section, terms and concepts are clarified for the reader by listing definitions for the prominent topics covered in the research project. Hofstee (2006), stated that this is necessary to create effective communication and to prevent misunderstanding. These terms and concepts will be listed in alphabetical order.

- Conventional farming: “*Agricultural practices based on crop production technology improvement with special attention on high yielding hybrid* *seeds, inorganic fertilisers and pesticides, agro-equipment and machinery that is driven by non-renewable fossil fuel”* (Dixon, Gulliver, & Gibbon, 2001).

- Eco-Agriculture: “*Eco-Agriculture is an ecological rather than an industrial approach to food and fibre production. Eco-Agriculture minimizes adverse environmental effects and promotes soil conservation and construction. Soil is viewed as a complex and living entity and considered the prime capital asset of a nation. Eco-Agriculture is fundamentally a holistic system. Its basic premise is that all facets of creation are intimately interrelated and that there is an intrinsic harmony to the natural order which is governed by certain laws. Man's role is that of the ‘faithful steward’ and—in the person of the farmer—nature's partner. Agriculture is seen as creative rather than mechanistic because it is fundamentally a biological and living process rather than a technological and industrial one”* (Merrill, 1983).
- Fertigation: “*The practice of supplying crops in the field with fertilizers via the irrigation water is called fertigation*” (Sandal & Kapoor, 2015, p.114).
- Integral theory: “*The word integral means comprehensive, inclusive, non-marginalizing, embracing. Integral approaches to any field attempt to be exactly that: to include as many perspectives, styles, and methodologies as possible within a coherent view of the topic. In a certain sense, integral approaches are “meta-paradigms,” or ways to draw together an already existing number of separate paradigms into an interrelated network of approaches that are mutually enriching*” (Esbjörn-Hargens, 2010, p.1).
- Soil quality: “*It is the capacity of a soil to function within (and sometimes outside) its ecosystem boundaries to sustain biological productivity and diversity, maintain environmental quality, and promote plant and animal health*” (Brady & Weil, 1990, p.873).

- Sustainable development: "*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (Du Pisani, 2006, p.83).
- Transdisciplinary Research: *"We use the term transdisciplinarity to refer to research that (1) tackles real life problems, (2) addresses the complexity of these problems by involving a variety of actors from science and practice and accounting for the diversity of their perspectives, and (3) creates knowledge that is solution-oriented, socially robust, and transferable to both scientific and societal practice"* (Hoffmann, Pohl, & Hering, 2017, p.1).

1.7 Significance of the Study

The holistic TDR approach to the triad of People, Planet and Profit in the context of an operational commercial vegetable farming enterprise is an innovative approach to strategic business model change management in NZ. Therefore, it would be significant for ASW to use broad stakeholder inputs as part of a strategic change process (Botha et al., 2014). Breaking with the traditional view of soil health as a mere measure of production (Haney et al., 2018), and by looking at soil health from a holistic point of view where soil is fundamentally part of food security and biodiversity (McBratney et al., 2014) will form the basis of this study.

This study is necessary to discover the opportunities available for ASW to implement a sustainable farming model and to investigate the practicality of some of the theories of eco-agriculture in the local climatic conditions and with current production practises and management teams. It is vital to make a start, using the TDR framework to tackle these real-life problems and to build the momentum by involving stakeholders from a broad spectrum of influence, to create knowledge that is solution orientated.

1.8 Outline of the Thesis

The thesis consists of five chapters. An introduction (Chapter 1) is followed by the literature review (Chapter 2). In Chapter 3, the research design and methodology are presented after which the findings are discussed in Chapter 4. Chapter 5 deals with a summary, the conclusion as well as recommendations. The appendixes contain additional material supportive of the research project, as shown in (Figure 2).

Figure 2: Outline of thesis.

1.9 Summary

The researcher had to determine boundaries for the project (Brehmer, Podoynitsyna, & Langerak, 2018). Setting the boundaries was not easy. The researcher discovered early on in his endeavours that saving the planet, and humanity at large, was not within his scope of influence but that a much narrower, and more focused approach to implementing change was required.

A literature review will follow where the researcher aims to discover what is already known about his areas of interest so as to “not re-invent the wheel” as described by Bell et al. (2019).

Chapter 2: Literature Review

2.1 Introduction

There is a mounting concern that agriculture and the world food systems it supplies are not sustainable. Humanity is facing a sustainability crisis. Food production and the conservation of biodiversity and ecosystems are worldwide at risk, with 38% of the earth's surface being employed for agricultural purposes (Reganold & Wachter, 2016).

Customers demand greater innovation, near-perfect quality, faster, lower-priced produce with easier access (Kotter, 1995). How do commercial vegetable producers in the Waikato, implement the necessary change to satisfy their customers' demands? Additionally, agricultural intensification in NZ will threaten both the environment and the sustainability of food production (Campbell et al., 2012). Furthermore, there is an ongoing debate in New Zealand (Griffin, 2019), around the loss of productive agricultural land to urban encroachment due to population growth and property value.

As a commercial vegetable producer, farming in the Matamata region of the Waikato District of New Zealand, ASW could potentially benefit from taking cognisance of the theory and related research outcomes of sustainable agricultural principles as depicted in this literature review.

This chapter is made up of five sections: The introduction (Section 2.1) is followed by an introduction to the company and its geographical influencers (Section 2.2). Section 2.2.1 deals with ASW a commercial vegetable farming operation which forms an integral part of the co-creation and execution of this research project. The literature reviewed in relation to ASW included the business vision and mission in order to contextualise its position regarding sustainability.

This is followed by Section 2.2.2, where the local influences and the geographical locality of the Matamata farming operation is relevant. Vegetable production is a high-intensity farming operation and local conditions, whether they be social, environmental or financial, might have a significant impact on any research and results.

The literature review is then widened to a regional level in Section 2.2.3, where the Waikato region, with its potential regulatory influence, is presented to the reader. These three sections collectively create a context for the reader, where company dynamics, local influences and/or regional issues might influence the decision-making processes for this research project.

Section 2.3 exposes the reader to the concept of operational and strategic change for the business operation. Identifying the “why” and the “how” is important for the purpose of this study since there is a current status quo and there is a need to change to an operational model that adheres to the principle of the “common good”. This concept from TDR will be discussed later.

The principles of sustainability and eco-agriculture as a broad concept is then reviewed in Section 2.4. The options available to ASW as an agricultural company and the reasons why other companies have moved away from conventional farming are introduced here. Finally, the specific topic of soil health is brought forward as the eco-agricultural area where ASW could focus their efforts to become more sustainable.

In Section 2.5, the motivation for using a transdisciplinary framework for research is introduced, along with the theoretical, axiomatic basis, for transdisciplinarity. It will be shown why this framework is applicable to addressing so-called “wicked” complex problems.

Because the company approved research project aims to bring about innovative strategic change, the concept of innovation and the factors involved with innovation will be dealt with in Section 2.6. Finally, Section 2.7 will summarise the core issues from the literature review.

2.2 The Company and its Geographical Influencers

2.2.1 A.S. Wilcox and Sons Ltd

The Wilcox Group of Companies is involved with growing, packing and distributing fresh produce throughout NZ with facilities at Pukekohe, Ohakune, Northland and the Waikato in the North Island, and Rakaia in the South Island (Figure 3)

Figure 3: The ASW footprint in New Zealand with operations in Northland, Pukekohe/Franklin, Matamata and Ohakune on the North Island, and in the Canterbury Region on the South Island (Retrieved from: Wilcoxgoodness, 2018)

Companies within this group are privately owned by the Wilcox family which has been associated with vegetable growing since the early 1930s. They manage a production base of 1500 ha with 170 permanent staff. They grow potatoes, onions, carrots and 'utility crops" in rotation to the main vegetable crops. Their brand names (Figure 4) are well recognized throughout NZ (Woolworth's New Zealand Limited, 2019).

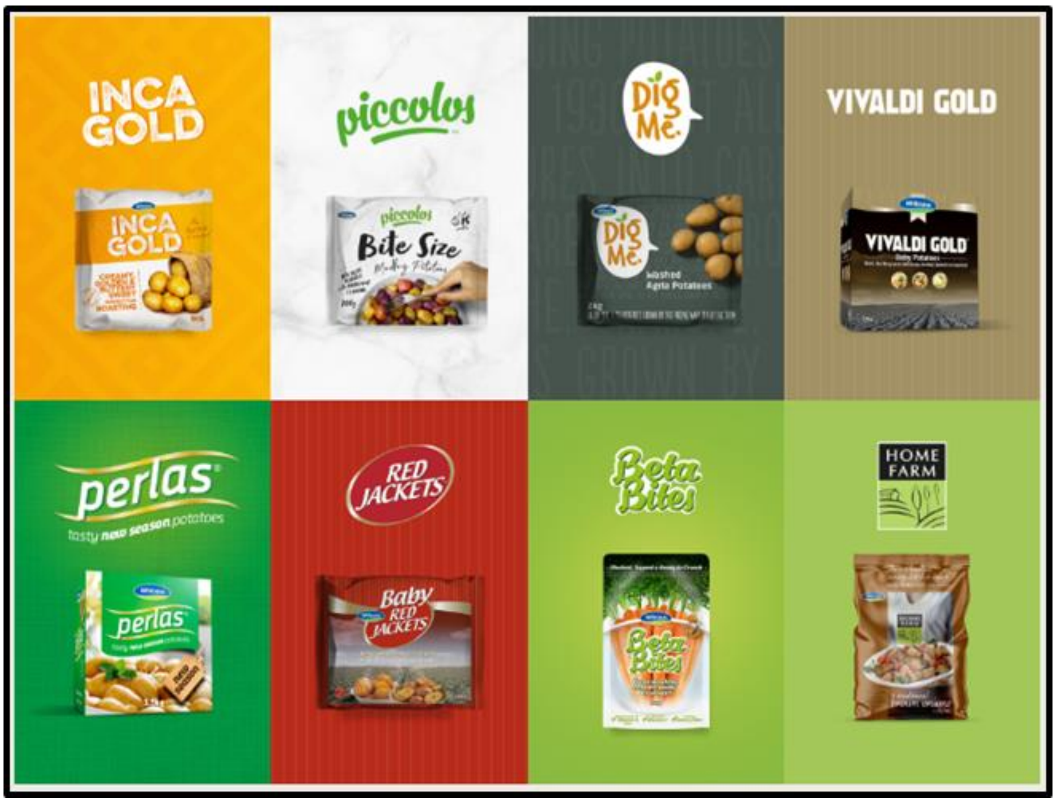

Figure 4: The ASW brands represented in the domestic market of New Zealand (Retrieved from: Wilcoxgoodness, 2018)

The Wilcox legacy in New Zealand starts with the arrival of Henry Wilcox aboard the 'Chile' in Auckland. He was 19 years old when he arrived on the 19th of December 1869. Henry was of Irish descent and began his career in New Zealand as a gold miner at Thames (Wilcox, 2018).

In 1881 he purchased a property of 120 acres at Buckland, south of Auckland. Today, Buckland is near Pukekohe where members of the Wilcox family has established the headquarters of ASW.

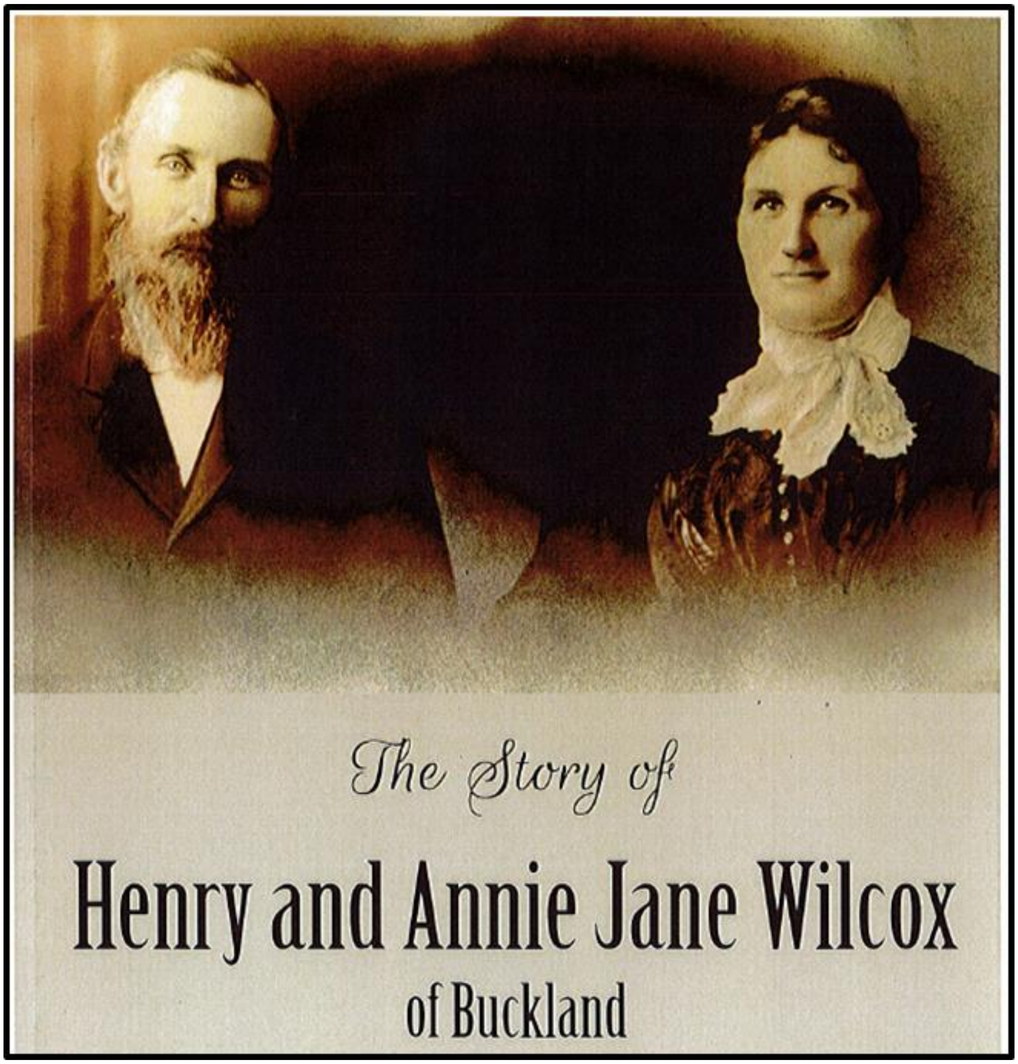

Figure 5: Henry and Jane Wilcox, the first of the family to arrive in New Zealand in December 1869 (Source: Wilcox, 2018)

Henry developed the property into one of the best dairy farms in the Franklin District. He married Annie Jane Greer (Figure 5), also from Irish descent on the 20th of August 1883 (Wilcox, 2018). Together they had seven sons and six daughters. The founder of ASW, Arthur Sydney Greer (Syd) Wilcox was born on the 3rd of September 1904 at Buckland (Figure 6) south of Pukekohe. He was the youngest child of Henry and Annie Jane Wilcox. In 1919 he started work on the family dairy farm, Willowstream, at Buckland (OTM Limited, 2004).

This part of the company's history is an indication of their continuous efforts over time to allow future generations to continue doing what they are doing as per the definition of sustainable development (Du Pisani, 2006).

Figure 6: Buckland, south of Auckland where Henry Wilcox had a farm. (Retrieved from: Google Maps, 2019a)

A 48-acre dairy farm with a herd of cattle, located on Union road purchased by Syd's father, came into Syd's possession when he married Belle Stuart. Syd purchased some onion seeds from a friend, Gordon Brownlee, and planted his first half an acre of Pukekohe Longkeeper onions in 1932 (Wilcoxgoodness, 2018).

The good aspect of the land, fertile soil, and relatively frost-free climate made Pukekohe into a favourable area for market gardening. What made this even more ideal was the city of Auckland's urban development which started to encroach onto market gardening land in Panmure and Mangere.

Today, ASW is still a family owned business involved with vegetable production with deep rooted core values.

Figure 7: The core values of A.S. Wilcox and Sons Ltd; Respect at our core; Expect the best; Together growing (Retrieved from: Wilcoxgoodness, 2019)

The core values (Figure 7) of the company are defined as:

- Respect at the Core - commits to respect for the land, people and relationships with all voices being heard.
- Expect the Best: Responsibility is shared, and personal leadership is valued.
- Together Growing: Personal growth, challenging the status quo and innovating for better outcomes.

The company's purpose statement reads as follow: ***Growing healthy communities from the ground up by delivering goodness and value to our customers*.**

Societal, ecological and financial needs are implied in the company's purpose statement. The researcher postulates that by implementing sustainable farming principles into the business model and by engaging with the community of stakeholders, it will contribute to the growth of a healthy society. The focus on soil health and plant health will deliver on the promise of goodness and value for their customers.

ASW has been farming in the Matamata area since 1984, and the climate and soil type found in Matamata suits the requirements for growing potatoes, onions, and carrots. The central location to Hamilton and Rotorua holds potential for future growth. The researcher will elaborate in more detail about these factors in Section 2.2.2.

2.2.2 Matamata

Matamata is situated in the Matamata/Piako district of the Waikato region of NZ. Matamata (Matamatanz, 2018), is well known for its dairy (NZFarmer, 2018), and horse industries (Waikato Stud, 2019). It also attracts many visitors to the Hobbiton Movie Set (Figure 8). The town has a population of 7,920 as of June 2018. (StatsNZ, 2018).

Figure 8: The Hobbiton Movie Set Tour attracts thousands of tourists to the Matamata Region annually (Retrieved from: Hobbitontours, 2018)

There are currently more than 3000 visitors to the Hobbiton movie set daily. Tourism to the town is increasing. This is best demonstrated with Hobbiton applying for a change to its resource consent from 300,000 to 650,000 people to visit them annually, and this may lead to growth in the commodities and services sector with the resulting increase in pressure on land and infrastructure.

The Hobbiton tourist destination is New Zealand's third largest and estimated to bring $78m to the district annually (Tantau, 2019). The proposed $1.5 billion new television series (Lord of the Rings) by Amazon is a case in point (Theunissen, 2019). The town has a rich history as described by Joan Stanley. From a soft system and integral theory perspective (Checkland, 2000; Esbjörn-Hargens, 2010) it is important to understand the context of a place and the people that lived there and how it came to the current situation. Soft systems and integral theory will be discussed in Section 2.5.

The business operation is situated in this rich context and must be cognisant of the social, historical and environmental dynamic if it wants to be an acceptable part of the fabric of the lives of the people and the world it operates in. The history of the town is recounted here as it had an impact on the decision whom to involve in the interview process and strongly supports the argument of Matamata's regional importance and influence on ASW. It also emphasises the urban encroachment predicament.

Excerpts from MATAMATA'S HISTORY (As described by Joan Stanley).

"Matamata means 'headland'. This was the name of a new pa established in 1830 by Te Waharoa, the famous Ngatihaua chief, on a ridge of high ground projecting into the swampy valley of the Waitoa River near Dunlop Road, a few kilometres north-west of present day Waharoa.

In 1885 the Thames Valley and Rotorua Railway Company, of which Firth was a promoter, constructed a railway from Morrinsville across the plains to Matamata. The selection of the site of a small railway station in the middle of the plain began the development of the future town of Matamata from a nucleus of a few houses scattered around the station and the railway line.

The township of Matamata, which was still a tiny settlement, was surveyed into town sections with provision for wide streets and a recreational area at the *central domain. The surveyors enclosed the new settlement on two sides with a 40-metre-wide plantation reserve which over the years has developed into the Matamata Centennial Drive, now a botanical park with a wide variety of trees from all over the world.*

Since 1885 Matamata has grown from a small scattering of houses around a railway station to a rural servicing town which provides for the commercial, medical, educational, religious, industrial and recreational needs of the residents of both the town and its rural hinterland. In doing so it has developed its own distinctive character" (MatamataPRA, 2019).

There is a strong cultural bond between the land, the river and the people of the town. It comes as no surprise then that environmental pressures are mounting on the farming community to manage clean rivers, phosphate build-up, nitrogen leaching, sediment control and bacterial contamination of the rivers to a higher standard (Waikato Regional Council, 2012).

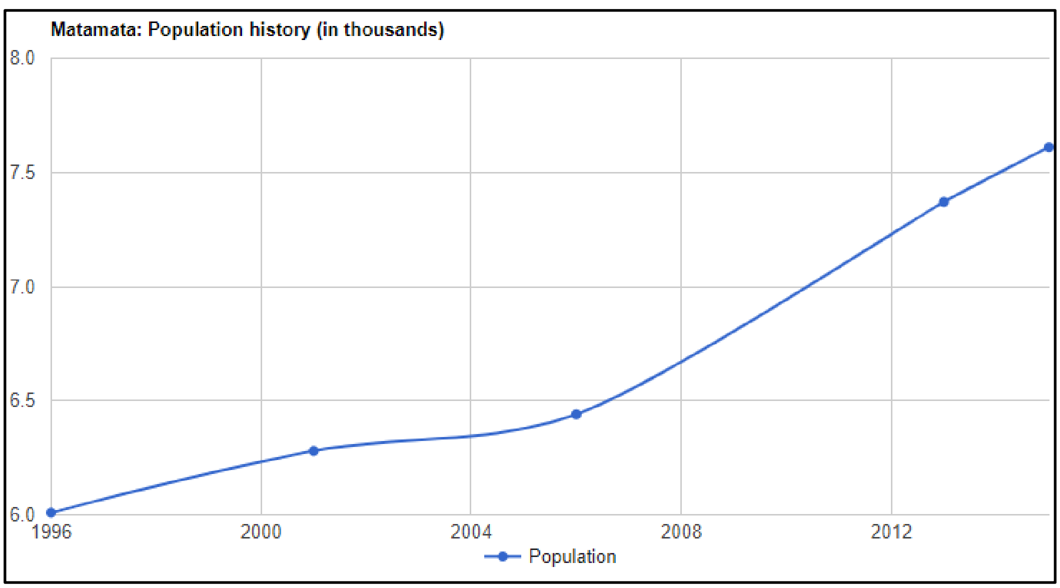

Figure 9: Matamata population growth measure from 1996 to 2018 (Source: Population City, 2019)

In 1996, the town of Matamata had a population of 6001 people. Twenty-two years later, the population figure rose to 7920 (Figure 9). It is not only the pressure on residential developments that drives these expansions but also the tourism industries' demands for accommodation in Matamata (Matamata backpackers, 2019).

There is an ongoing debate in New Zealand around the loss of productive agricultural land to urban encroachment due to population growth and property value (Griffin, 2019). Additionally, cropping on a large scale next to urban areas has the potential for conflict of interests. Noise, dust, chemical sprays, light pollution, and other factors increasingly make it difficult for farmers to continue farming in the traditional "chemical" way (Mayor Jan Barns, interview, May 28, 2019). For example, the proximity of the McCarville farm (Figure 10) to the Matamata town have led to numerous incidences of conflicts of interest in the past (own experience).

Figure 10: Matamata town in 2017; indicating the proximity of the town to agricultural land at the McCarville farm (Source: Google Earth, 2019)

As seen in (Table 1), arable land value in the Waikato ($37 313/ha) is not as high as land in the Hawkes Bay ($184 458/ha) or the Bay of Plenty (120 324/ha) regions where the price is driven by the fruit industry. Waikato compares well to the national average.

Local forces in the Matamata district dictates much higher prices ($100 000/ha) than the Waikato figure though, and the availability of lease land to commercial vegetable producers is becoming scarce (Realestate, 2019). Competition for land is putting pressure on vegetable producers to intensify their efforts to maintain their position in the market.

Table 1: Land value in New Zealand as on February 2019: The regions of New Zealand, land use within those and the dollar value per hectare sold are reflected in this table (Retrieved from: Interest.co.nz, 2018)

$/ha - February 2019	*All*	*Arable*	*Dairy*	*Finishing*	*Forestry*	*Grazing*	*Hort*	*Special*
New Zealand	**22,462**	**35,495**	**35,807**	**28,872**	**7,781**	**9,700**	**164,176**	**295,385**
Northland	15,732	77,809	17,741	28,506		9,545	161,015	
Auckland	49,853	180,958		37,361		8,269	423,820	301,747
Waikato	29,273	37,313	37,512	36,781		12,620	30,560	
Bay of Plenty	59,659	120,324	47,962	36,230	12,134	13,518	388,580	
Gisborne	28,468			28,468	15,152	9,372	116,683	
Hawkes Bay	13,299	184,458		15,934	42,636	9,312	494,237	
Taranaki	33,153	17,216	38,399	38,133		10,355		
Wang/Manawatu	13,182	19,442	24,425	30,111		7,751	197,723	
Wellington	8,586	20,087	34,447	28,487	1,568	7,439		
Nelson	20,664	12,718	30,243	23,740	6,050	10,078	153,946	
West Coast	8,244	12,510	8,932		7,781	6,376		
Canterbury	23,265	39,710	54,229	27,707	4,615	11,332	116,409	22,331
Otago	18,276	13,508	37,500	29,385		10,881	90,859	
Southland	25,088	39,903	36,347	25,088		13,840		

The proximity of Matamata to Rotorua with its own tourist attractions, Hamilton as the biggest city in the region with its airport, and Tauranga with manufacturing capacity and a port for import and export, contributes to its high value-proportion for local businesses (Figure 11).

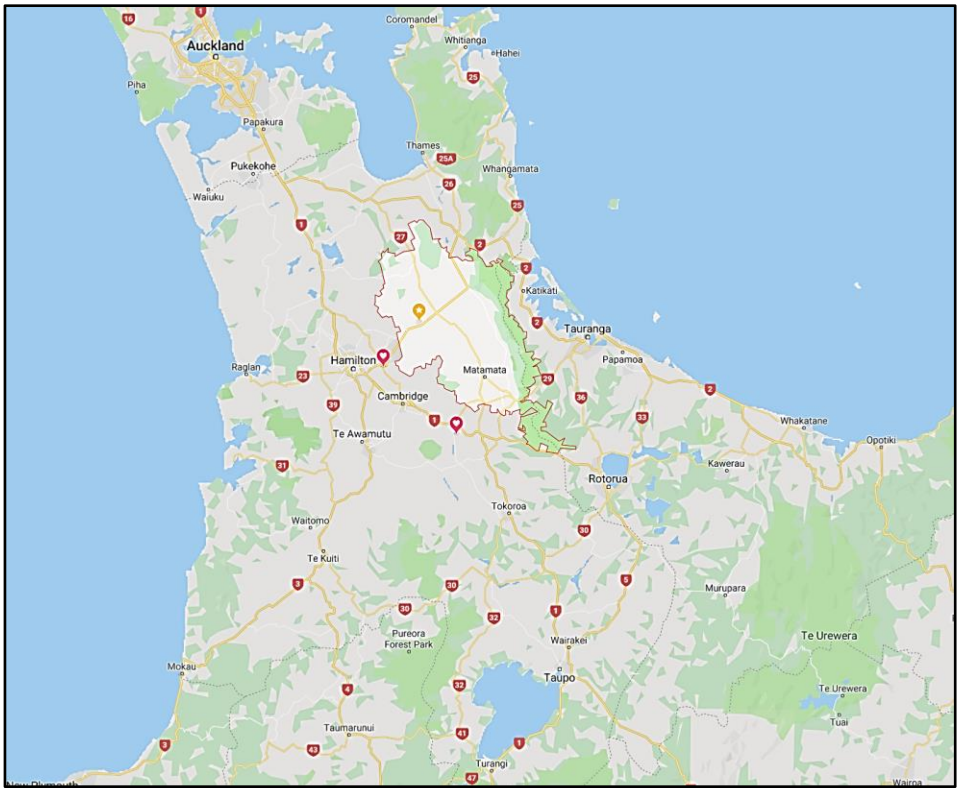

Figure 11: The district of Matamata/Piako is centrally located between Tauranga, Rotorua, Taupo and Hamilton (Source: Google Maps, 2019a)

2.2.3 Waikato

The Waikato is a local government region of the North Island of NZ (Figure 12). It has a population of 468 800 as on June 2018 and consists of 2.5 million ha. The biggest city in the region is Hamilton, with 241 000 people (StatsNZ, 2018).

The name is generally considered to be a compound of Wai (water force) and Kato (flow), but there are different interpretations from different iwi. The Waikato river is New Zealand’s longest river. It has its origins on the slopes of Mt Ruapehu, from where it runs for 425 kilometres until it reaches the ocean at Port Waikato (Moon, 2018).

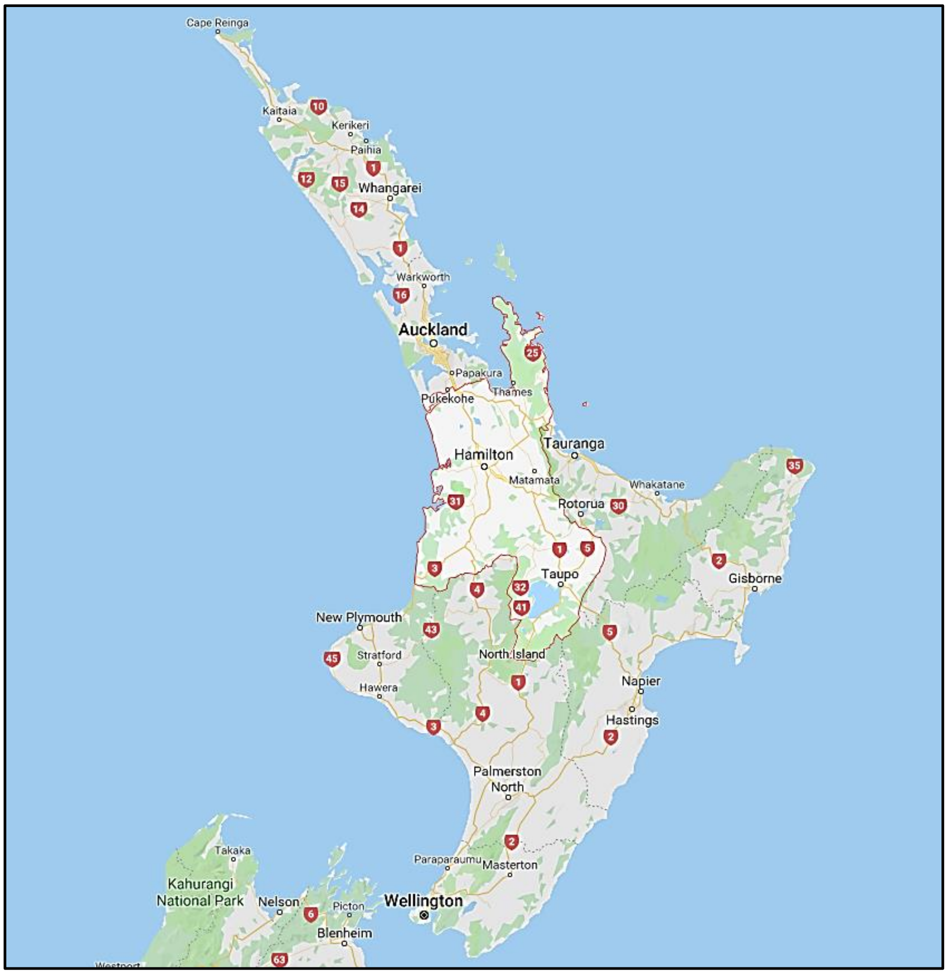

Figure 12: The Waikato region of New Zealand. (Retrieved from: Google Maps, 2019b)

It is one of New Zealand's major sources of hydro electrical power and drives the turbines of nine electrical stations. It is enjoyed by many for recreational purposes and supplies food and resources to many more from its banks and clean water. The river is a significant feature with important cultural value for the people of this region (Moon, 2018).

The health of the river system is equally important. This is emphasized by the Waikato Regional Council's "Clean River Initiative" (Waikato Regional Council, 2019b) which identifies the river's sense of place through the interconnections of land with water as follows:

- *“The rivers contribute to a sense of community and sustaining community wellbeing.*
- *The rivers are an important part of whānau/family life, holding nostalgic feelings and memories and having deep cultural and historical significance.*
- *For River Iwi, respect for the rivers lies at the heart of the spiritual and physical wellbeing of iwi and their tribal identity and culture. The river is not separate from the people but part of the people, “Ko au te awa, ko te awa ko au” (I am the river and the river is me).*
- *The rivers are a shared responsibility, needing collective stewardship: kaitiakitanga – working together to restore the rivers. There is also an important intergenerational equity concept within kaitiakitanga.*
- *Mahitahi (collaborative work) encourages us all to work together to achieve common goals”*.

A strategic change is proposed for ASW. This means that possible changes in policy should be considered. It is known that a Regional Policy Statement was published that covers the Waikato and the Waipa river catchments and that these policies have specific directives for reducing nitrogen, phosphorus, and sediment. Bacterial contamination loading of streams and rivers is also to be regulated.

Agricultural land use, including a range of other activities, will be limited to align with biophysical capabilities of the land and the effects on lakes rivers and wetlands (Waikato Regional Council, 2019a).

The operations of ASW in the region will have to comply with similar policy changes in the foreseeable future. For this reason, production of crops under reduced nitrogen and phosphorus loading of the land and different tilling approaches (to curb sediment loss) must be developed and implemented. Environmental influences like rainfall, frost, temperatures, and other factors are putting commercial vegetable operations in the Waikato under pressure to maintain their position on the world market.

Interaction with various stakeholders during the study brought the topic of change to the forefront and it was clear to the researcher that this philosophy of co-existence between farmers, the environment, people, and the regulatory institutions would be an option for ASW if they wanted to maintain, but also grow, their position in the market. They would have to change if they wanted to become a thriving business. If there is a need for change and how to implement this change will have to be investigated.

2.3 The Process of Change

Guston (2001) mentions a possible challenge facing transdisciplinary researchers. Managing the boundaries between science and policy with some parties involved at these boundaries "*expressing concerns with the scientization of politics and the politicization of science*" is something the researcher will have to consider.

In the business environment, problems are often complex and solving these problems would require a deeper investigation of the real issues at hand. Checkland (2000) proposes Soft Systems Methodology (SSM) as a model for management of change and Rodgers (2008) is of the opinion that the ability to deal effectively with organisational change is critical to business success.

Change could be voluntary, but it could also be forced upon a business through environmental, financial or social pressures. Examples of how environmental issues have forced agriculture to change in the past are:

- Almeria, (Spain) where the protected structure industry had to convert to sustainable biological farming after exports of fresh produce to Europe were returned due to agrochemical residues, and a ban on exports were imposed (Wolosin, 2008).
- In the Jordan valley of Israel, the Culiacan region of Mexico, and now almost in all open-field tomato production areas in the world, open field

production of tomatoes has become challenging after the devastating Tomato Yellow Leave Curl Virus (TYLCV) became established through its vector *Bemisia tabaci* (whitefly), (Hebrew University, 2007).

- Financial pressures contributed to the change implemented by ZZ2®, an agricultural business in South Africa. It converted to "Natuurboerdery®" (Nature Farming) as a result of inorganic fertiliser cost increases and the devaluation of the currency (Taurayi, 2011).

In New Zealand, three examples of environmental pressures that forced change come to mind:

1. *Pseudomonas syringae pv. actinidiae* (Psa) is a bacterium that can result in the death of kiwifruit vines. It was first discovered in NZ in November 2010 and rapidly caused widespread and severe impacts on the New Zealand's kiwifruit industry (Goldson et al., 2015).
2. The potato industry was hard hit by the devastating Tomato Potato Psyllid (TPP). *Bactericera cockerelli* is the insect responsible for transmitting the bacterium *Candidatus Liberibacter solanacearum*. Both the plant and the tubers are adversely affected (Jamieson, Page-Weir, Griffin, Redpath, & Chhagan, 2016).
3. As recent as September 2018, a new virus; Potato Mop-Top Virus (PMTV), was found in NZ. The virus is transmitted by the soil-borne fungus which causes Powdery scab (*Spongospora subterranean*) and can only survive long-term in the potato plant or in the fungus. It has become the latest challenge to biosecurity for the industry (PotatoesNZ, 2019).

In Figure 13, Rodgers (2008, p. 4) lists three perceived views on how change happens in organizations.

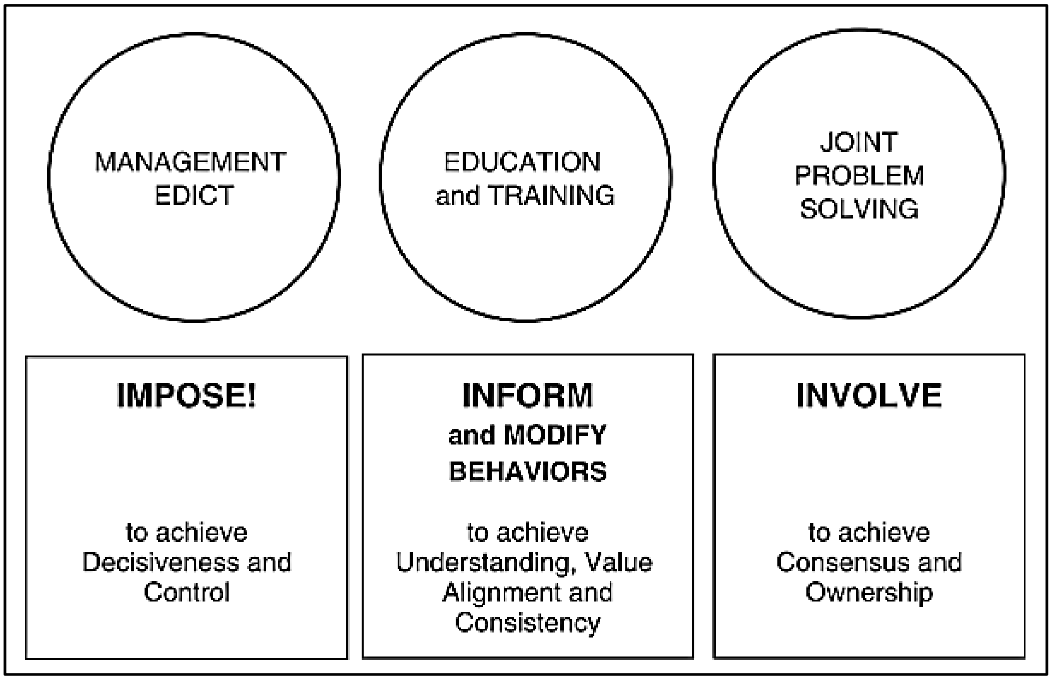

Figure 13: Rational approaches to change encompassing the management edict, education and training and joint problem solving (Source: Rodgers, 2008)

1. The “Management edict” sees change as being imposed by management to achieve decisiveness and control.
2. The focus of “education and training” is on explaining the required changes and modifying the behaviours of staff to achieve alignment between people’s values and ensure consistent behaviours across the organization.
3. The “joint problem solving”, argues in favour of involving a broad constituency of people to achieve consensus in decision-making and to create a sense of ownership for the change.

For the duration of this study, the researcher’s position within the organization did not allow him to impose decisions under the management edict. Neither did the time frame allocated to the research project, allow for the “education and training” edict to be followed. The researcher had to rely on personal influences and what could be practically demonstrated. It was necessary to find a methodology which would be a catalyst for change and convince stakeholders accordingly.

Joint problem solving that allowed for inclusivity, and that conformed to the collaborative approach of the study, was proposed. The organizational change explains the movement of an organization from the known (current state) to the unknown (desired future state), (Hussain et al., 2018).

To introduce EA principles into the organisation will require implementing change. Eight steps of transformation are required (Kotter, 1995):

1. Establishing a sense of urgency.
2. Forming a powerful guiding coalition.
3. Creating a vision.
4. Communicating the vision.
5. Empowering others to act on the vision.
6. Planning for and creating short term wins.
7. Consolidating improvements and producing still more change.
8. Institutionalising new approaches.

This research project requires the researcher to implement not only change on a scientific level with production systems but ultimately, also introduce cultural change into the team responsible for implementing the philosophies of EA. This process might take five to ten years (Kotter, 1995).

Hardy, Palmer and Phillips (2000) developed a model for the use of discourse to mobilise resources (Figure 14). Three so-called circuits are described. Starting with the Circuit of Activity, new ideas with a broad outcome in mind, are introduced. This is followed by Performativity, where ideas are ‘heard’ and embraced and discussed in a constructive manner.

The final Circuit of Connectivity shows that ideas are taken up and practised in some situations, new (often innovative) practices can now emerge and influences the future direction and discussion. The process is iterative and non-linear. Such a process allows the researcher to take stakeholders and others in society on a co-created journey to a mutually acceptable outcome.

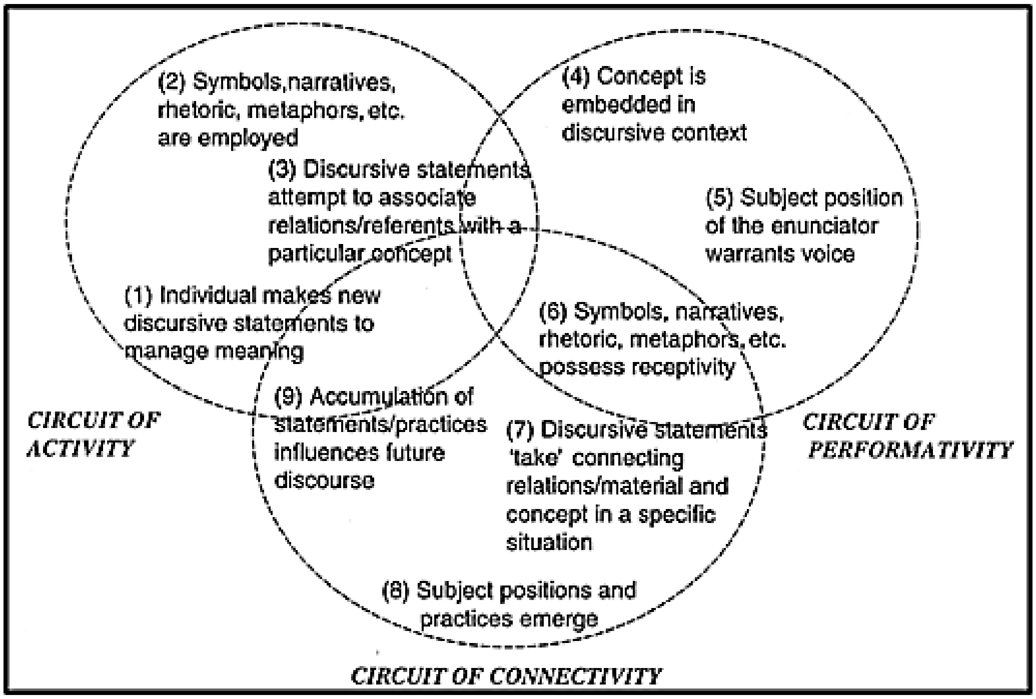

Figure 14; A model of discourse as a strategic resource (Source: Hardy et al., 2000)

The alignment of people and processes with new ideas is one part of the equation. Sustainability is part of the equation and is the process of maintaining change in a balanced fashion. It means that the exploitation of resources, the investments, technological development and enterprise change must be in harmony. The concept of sustainability will be addressed from this perspective, in the next section.

2.4 Sustainability

Historically, sustainability within the NZ agricultural context pivots around the following factors: Firstly, the arrival of European Settlers that triggered significant ecological changes post colonialization (Brooking & Pawson, 2010). Secondly, Post-World War II, NZ witnessed intensive use of new fertilisers and thirdly, during 1973 NZ lost the benefit of tariff protection at the time when the United Kingdom joined the European Common Market. The loss of this privilege led to NZ's reliance on market forces alone to provide sustainability (Haggerty, Campbell, & Morris, 2009; MacLeod & Moller, 2006).

Within NZ, an academic reflection on Māori and their view on sustainable agricultural practices would be deemed appropriate. However, this research specifically focuses on how ASW could embed sustainable agricultural principles in a Waikato based, commercial vegetable farming operation, in such a way that it will ensure a thriving business for the future.

Table 2: Māori values and human ends associated with sustainable agriculture (Source: Campbell et al., 2012)

Māori values and human ends	
Value/Human-end	**Definition**
Manawhenua	Control over resources
Whanaungatanga	Togetherness
Arohatanga	Care, Love, Respect
Manaakitanga	Hospitality, Kindness
Wairuatanga	The spiritual dimension
Kaitiakitanga	Guardianship
Tino Rangatiratanga	Self-determination
Taonga Tuku Iho	Holding and passing down protected treasures – may include knowledge, objects or natural resources
Whakapapa	Genealogy, lineage, descent

Nevertheless, the researcher finds the Māori goals and values associated with agriculture (Table 2) relevant and valid for this research. These Māori values are reflected in the opinion of Bongiovanni et al. (2004, p. 361) where they state that one of the philosophical and religious issues that deserve attention, is stewardship (Kaitiakitanga). According to them, the current generation carries the responsibility of stewardship of land for the benefit of future generations.

Against a religious background (Wairuatanga), it is frequently seen as the obligation to preserve and improve God's creation. Human beings are envisaged as temporary caretakers of the land (Taonga Tuku Iho).

This opposes the view that natural resources are assets that may be exploited for the personal gain of the current property owner. Stewardship agriculture can only be sustainable if farmers use practices that are socially acceptable and profitable. This could be linked to the value of Arohatanga.

In Figure 15, sustainability is pictured by the Far North Community Development Framework as a tree with its roots in the soil (foundation) where the community and cultural values anchor the tree in the soil and feeds it through national, local and Māori development concepts, and by incorporating Human rights, the United Nations Sustainable Development Goals (SDG) and other international community concepts.

These concepts are channelled via the tree trunk (mission and vision), making use of participation, partnerships, engagement and collaboration mechanisms to branch through Economic, Social, Environmental and Cultural focus areas for sustainability to support communities in various ways (Far North District Council, 2019).

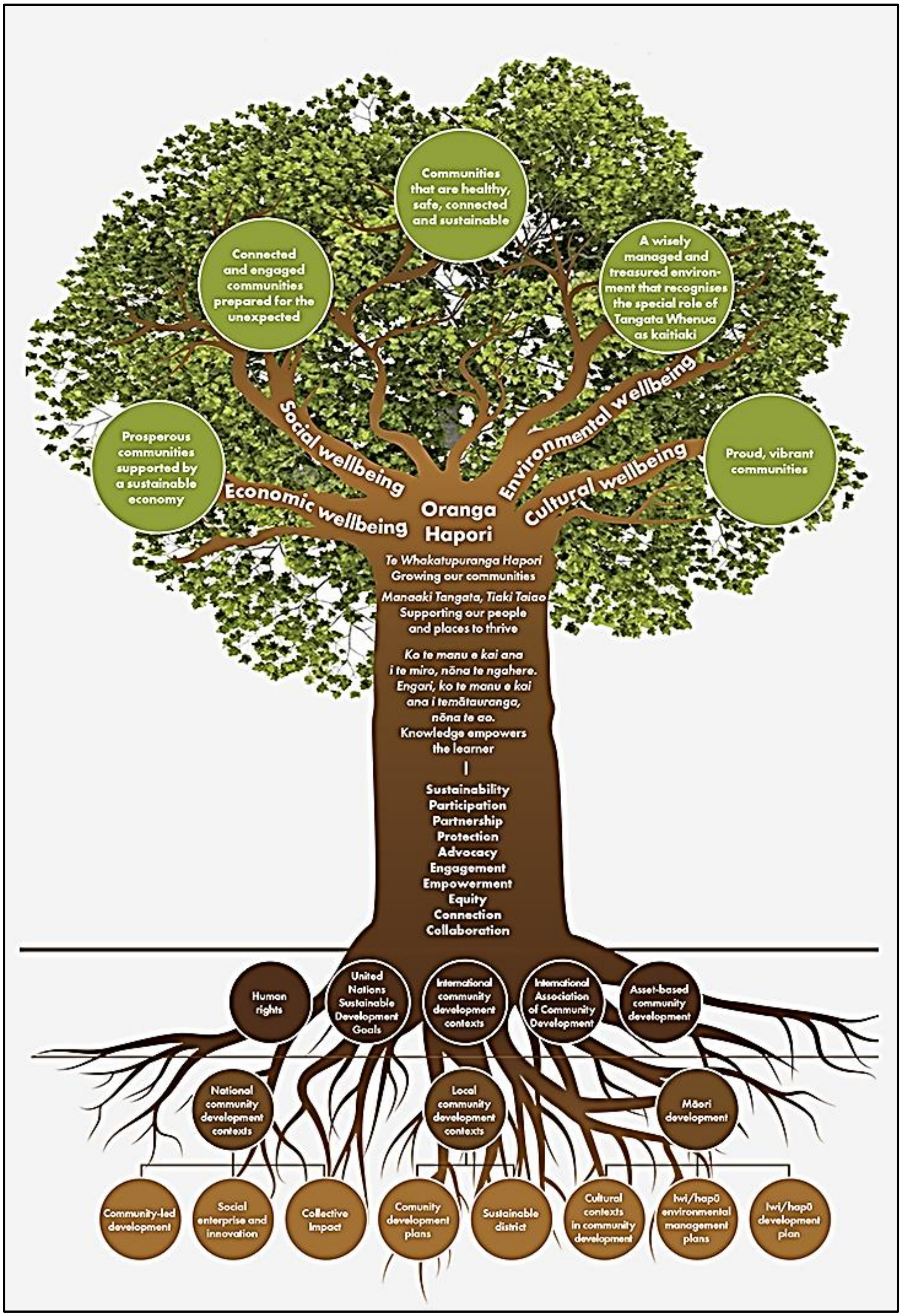

Figure 15: The Sustainability Tree; demonstrating the importance of economic, social, environmental and cultural wellbeing on sustainability. (Source: Far North District Council, 2019)

Sustainability has been debated and advocated in the past, and the question is how and by what means do we solve real-world problems (Moller et al., 2008). A literature review of possible interventions in farming philosophies (Hatt et al., 2016; Ingram, 2007; Renting & Van Der Ploeg, 2001), indicates that there might be possible solutions to satisfy the need for sustainability. The risk of implementing these principles as described by Taurayi, (2011) lays in setting the boundaries and accepting the fact a long-term strategy is required to implement change. Malherbe (2016) acknowledges the complexity of agricultural sustainability and warns that the implementation of sustainability on-farm would be a complicated task.

Different terms and definitions have emerged in recent years that refer to a range of minimum inorganic, resource- and energy-conserving, and efficient farming methods and technologies. Words such as biological farming, ecological farming, regenerative farming, nature farming, and eco-agriculture are terms used by people and groups to refer to various alternative agricultural production systems and practices (Parr, Papendick, Youngberg, & Meyer, 1990).

The researcher will not debate the differences between these “alternatives” but will build a case for change from the “conventional” to the “alternative”.

The 20th century marked the development of advanced inorganic regimes in the agricultural sector. “*Advances in understanding plant nutrition coupled with the slow release of fertilisers, foliar fertilisers, soluble nutrients and the development of plant tissue testing, have all improved the yield and quality of horticultural crops*” (Mikkelsen & Bruulsema, 2005).

A literature review on the topic of sustainability identified the United Nation (UN) as an organisation taking the lead in developing guidance for sustainable development (United Nations, 2015). The United Nations have identified 17 Sustainable Development Goals. In Figure 16, these 17 goals demonstrate the complexity of the wicked problem and emphasise the need for a transdisciplinary approach to solving a real-world problem.

Figure 16: The 17 Sustainable Development Goals of the United Nations. (Source: United Nations, 2019)

International agricultural organizations have adapted their own focus areas to guide them onto the sustainability path (Costagroup, 2019; Fonterra, 2019; Olamgroup, 2019; ZZ2, 2019).

2.4.1 Soil Health

Of the 17 Sustainability Development Goals, 13 of them involve soil one way or another (Keesstra et al., 2016). Four of the goals contain targets specifically related to soil and addressing soil degradation:

1. Target 2 (Zero Hunger),
2. Target 3 (Good Health and Wellbeing),
3. Target 12 (Responsible Consumption and Production),
4. Target 15 (Life on Land) from the United Nations Sustainable Development Goals (Figure17) relates to soil health as an integral part of sustainability (United Nations, 2015).

Figure 17: Soil is central to target 15.3 (Source: Keesstra et al., 2016)

In Figure 17, it is shown how Target 15.3 is central to the soil. Thus, sustainable soil management is the key to achieving these goals.

According to the USDA Natural Resources Conservation Service "*Soil health, also referred to as soil quality, is defined as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans" (USDA, 2019).*

The Waikato Regional Council describes soil health in terms of the following parameters: fertility, organic matter, physical condition and beneficial soil health in terms of bacteria and earthworms (Taylor, Cox, Littler, & Drewry, 2017). Equally important, Drobnik et.al (2018, p. 156) theorise that when assessing soil health, the spatial distribution of the assessments should not only focus on the absolute value of the soil quality but should also consider its spatial distribution, Concurrently Boruvka, Donatova, & Nemecek, (2002) postulate that site-specific management needs to consider spatial correlations and similarities in spatial distribution.

In Figure 18, the importance of soil health compromising the physical, chemical and the biological properties of soil, is highlighted. The sweet spot of "soil health” is where these properties interlock. The three circles are equal in importance, and one cannot function without the other (Gugino et al., 2009).

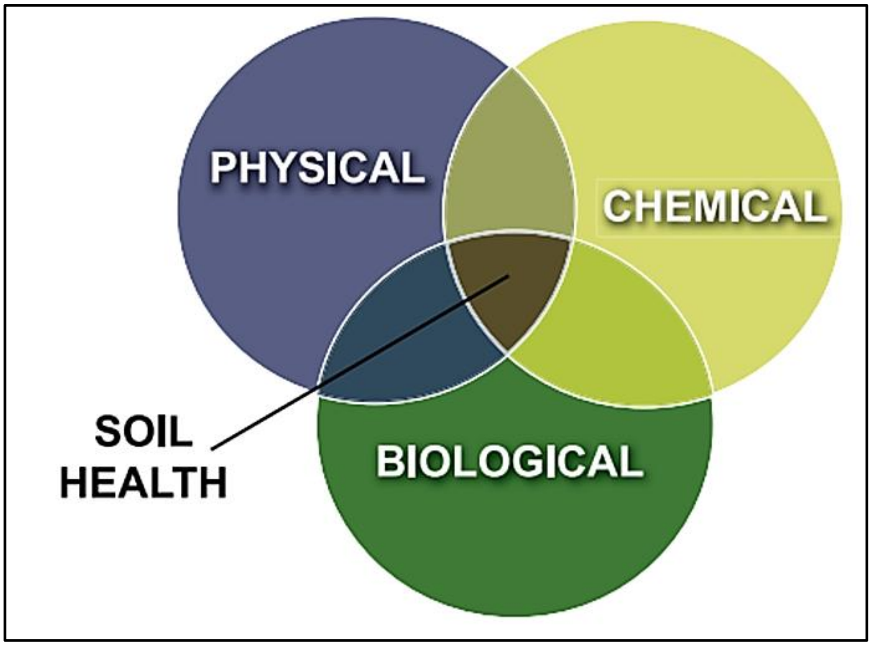

Figure 18: The concept of soil health encompasses the physical, biological and chemical components of the soil (Adapted from the Rodale Institute Moebius-Clune et al., 2017)

Soil quality is conceptualized as the major linkage between the strategies for agricultural conservation management practices and the achievement of the major goals of sustainable agriculture (Parr et al., 1990).

It is evident that there are different methodologies for assessing soil health: Condron et al. (2000) used soil respiration, mineralizable nitrogen (N), and the ratio of mineralizable N to organic carbon (C) as well as earthworm counts as the biological assessment for soil quality. They mention soil organic matter as an indication of soil structure. Haney et al. (2018, p. 164) argue that the amount of CO_2-C released by soil microbes in 24 h after the soil has been dried and rewetted indicates soil microbial activity. The Cornell Soil Health Assessment (Moebius-Clune et al., 2017, p. 26) considers the parameters in Table 3 as indicators of soil health. The importance of the physical, biological and chemical properties of soil in determining soil health is again emphasized.

Table 3: Soil Health Assessment Parameters (Source: Moebius-Clune et al., 2017)

Physical	Biological	Chemical
Available water capacity	Organic matter	Soil chemical composition
Surface hardness	Soil protein	Salinity and Sodicity
Subsurface hardness	Soil respiration	Heavy metals
Aggregate stability	Active carbon	

Moreover, Soil Foodweb New Zealand (Soil Foodweb NZ, 2016) uses a “direct counting” method to indicate numbers of fungi and bacteria present in the soil and then calculates the ratios between these. It distinguishes between active and total numbers. Included in their assessments are protozoa (flagellates, amoebae and ciliates). This technology was developed by Elaine Ingham (E. R. Ingham & Slaughter, 2004). Another method to measure soil microbial diversity proposed by (Couradeau et al., 2019) is the so-called BONCAT (bioorthogonal non-canonical amino acid tagging). This technology differentiates active microbes from extracellular DNA and dormant cells by fluorescence-activated cell sorting (FACS).

In addition, Figure 19 describes how soil health is central to the sustainability discussion. Crop health, food health, ecosystem health and farm health are dependent on soil health. The factors influencing consumer focus are nutrition, flavour and toxic-free products with a good shelf life.

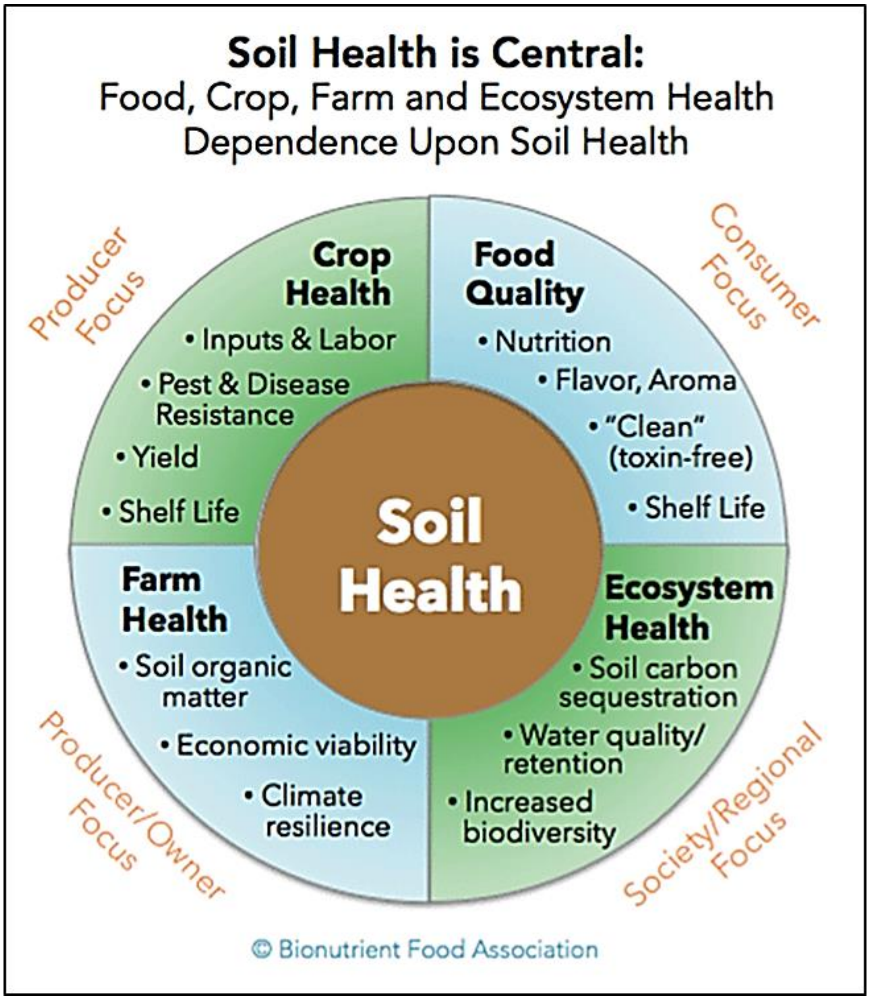

Figure 19: Soil health is an integral part of the puzzle to achieve sustainability (Source: North Coast Soil Health Hub, 2019)

There is a societal/regional focus on ecosystems health, and this relates to soil carbon sequestration, water quality/retention and an increase in biodiversity. The producer and or owner will focus on the farm health where organic matter content, the economic viability of the operation and climate resilience will be the main focus areas. For the producer, crop health will be a focus area. The emphasis on yield, pest and disease control, input costs, labour and the shelf life of products is placed here (North Coast Soil Health Hub, 2019). As a result of the above-mentioned producer/owner focus on farm health, compost application is suggested as a soil amendment in order to improve soil fertility (Agegnehu, Bass, Nelson, & Bird, 2016).

In many cases, prolonged intensive agronomic or horticultural cultivation causes gradual depletion of soil organic matter (SOM). Reduced SOM is frequently associated with lower soil biological activity and with deteriorating soil's physical properties. The result is overall reduced soil fertility. Repeated application of various types of organic matter, and especially of compost can reverse this negative process (Haynes & Naidu, 1998; Raviv, Lieth, & Bar-Tal, 2019). It is therefore inevitable that compost would be one of the pillars of EA principles.

2.4.2 Fertigation

The practice of delivering fertilisers to crops through the irrigation system is called fertigation (Sandal & Kapoor, 2015). Fertigation is commonly used in commercial agriculture to increase yield and to produce high-quality vegetables, with the combination of water and nutrients determined to be vital to success. García-Gaytán et al. (2018) consider fertigation of crops as a non-optional necessity.

Currently, ASW and most other onion producers in New Zealand, make use of ground spreading to apply dry, granular, inorganic fertilisers as a method to feed their plants (Rural News Group, 2019). Fertilisers are spread as a base application and then followed up with three or more side dressings using the same technology.

Exponents of fertiliser regimes highlight the following risks:

- The timing of the application is crucial because of weather influences and the availability of equipment (Bird, Curtis, Marais, McIndoe, & McNally, 2014).
- A percentage of nutrients are lost because of volatilisation, leaching, runoff and denitrification (Foundation for Arable Research, 2018).

- The application by way of tractors and spreaders contributes to soil compaction (Alaoui, Rogger, Peth, & Blöschl, 2018).
- Noise, dust, and light pollution become challenging to manage because of the proximity to urban areas (Landowner, personal communication, November 2018).
- The economic impact of inadequate fertiliser spreading accuracy on-farm performance (Yule & Grafton, 2013).

Internationally (Chartzoulakis & Bertaki, 2015), and in NZ, recent literature indicates that fertigation techniques have the potential to reduce fertiliser usage whilst maintaining profitable yielding crops (Deavoll, 2019). While this is the case, possible disadvantages include uneven delivery of fertilisers to the treated area and non-uniform distribution as a result of uncalibrated equipment (Chartzoulakis & Bertaki, 2015). As a matter of fact, the correct type of fertiliser must be used, the irrigation system must be capable of delivering fertiliser, and be compatible with the type of fertiliser and the mixing technique must also be correct (Environment Canterbury Regional Council, 2019). Essentially, fertigation techniques are crucial for the responsible management of water, fertilizer, and soil in sustainable food production (Drechsel, Heffer, Magen, Mikkelsen, & Wichelns, 2015).

Importantly, as part of a fertigation regime, elemental values of each nutrient are calculated and administered according to the corresponding growth curve of the specific crop (Thompson, Delcour, Berckmoes, & Stavridou, 2018). A centre pivot irrigation system is deemed to be appropriate and effective for various fertigation purposes within different environments. Fertilisers can be applied through such a system (Kushwaha & Kanojia, 2018).

2.5 Transdisciplinarity

The thesis of the current research is that it is possible to bring about the required change in an organisation to ensure that the business is sustainable and successful (thrives) by embedding certain modified operational practices, where the decisions are informed by a raft of perspectives and from a range of knowledge positions. The fact that different role players (internal and external) may have different views on what practices need to be changed, and how the company should respond to changes in the business environment, the natural environment and societal perceptions, is not simple to address.

Jordan and Davis (2015) support the notion that sustainable growth is a broadly shared idealistic dream for agriculture, in which Growing and other ecosystem services mutually increase to meet the future needs of humankind and the biosphere.

Accomplishing this vision will need an outcome-driven style that draws on all available procedures and technologies to design Agro-ecosystems that navigate the difficult trade-offs associated with reconciling sustainability along production, economic, and environmental performance dimensions.

"*To create such middle-way strategies for sustainable intensification, we call for strongly transdisciplinary research systems that coordinate integrative research among major streams of agriculture via ethical and philosophical orientation provided by purposive disciplines, such as applied ethics and design*" (Jordan & Davis, 2015, p.513).

Harris et al. (2013, p.2) mention that there is a need for research that addresses complex environmental concerns *to take "interdisciplinary and trans-disciplinary approaches".*

What is Transdisciplinarity? Cilliers and Nicolescu (2012, p.711) bring together the concepts of complexity and different knowledge bases ("realities") and the methods to effectively and fundamentally consider large open, real-world systems to broaden our knowledge of the world. They state that "*a unified complex theory of levels of reality is crucial in building sustainable development and sustainable futures*."

They highlight the fact that the infinite set of realities is universally interdependent. This gives rise to real complexity in the world. The axiomatic basis makes provision for and acknowledges contradiction and the open nature of knowledge. It is possible to always find more possible solutions, equally valid to complex problems.

The main objective of TDR is to:

- Acknowledge the complexity of a problem.
- To consider the diversity of scientific as well as real-world perceptions of problems.
- To connect case-specific and abstract knowledge and,
- Grow knowledge and practices that will advance the common good (Pohl & Hadorn, 2007).

TDR practices are issue-or problem-centred and prioritize the problem at the centre of research over discipline-specific concerns, theories, or methods. TDR is done for the 'common good', meaning that interventions must take into account consequences for a range of stakeholders and ensure, as best possible, that no new negative issues are introduced as a possible solution is implemented. TDR is focused on bringing together different knowledge bases, in the context of a specific situation, to generate new learning and knowledge (Hadorn et al., 2008).

Acknowledging that all credible knowledge sources should be treated equally makes transdisciplinarity well suited to conducting social research that involves synergistic collaboration between two or more disciplines with high levels of integration between the disciplinary sets of knowledge (Leavy, 2016).

Figure 20 demonstrates that TDR is an iterative and often recursive process of joint framing and structuring of the issue under investigation, analysis and subsequent synthesis of knowledge and understanding (Hadorn et al., 2008).

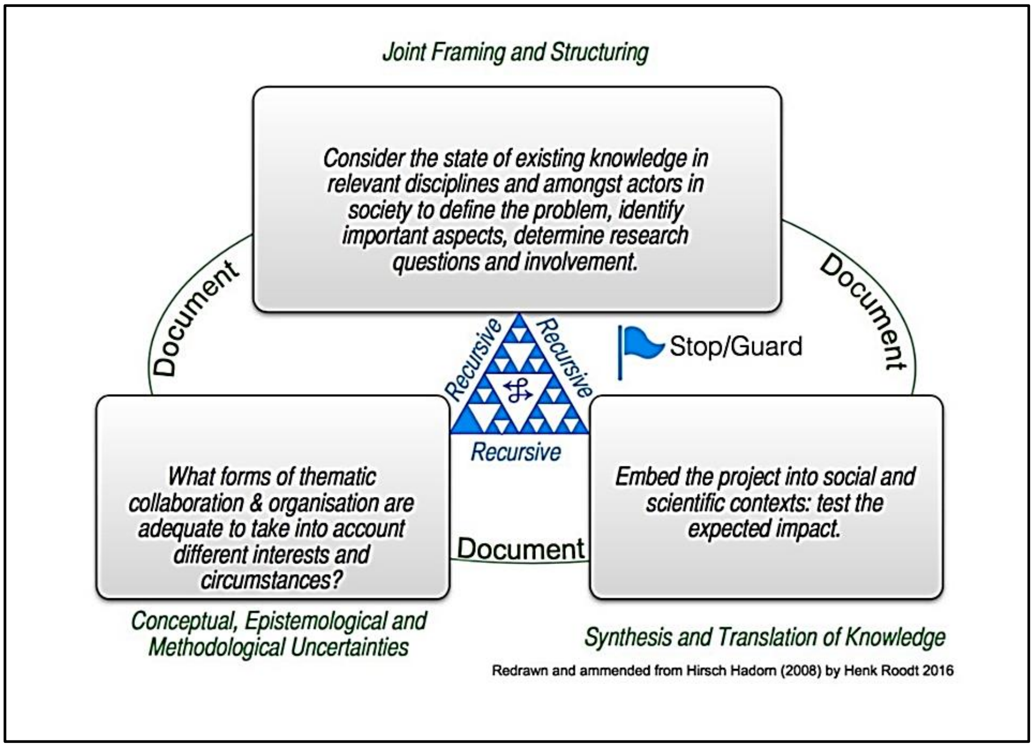

Figure 20: Synthesis and translation of knowledge (Source: Hadorn et al., 2008)

With complexity comes uncertainty and ambiguity. Often the stakes are high. The situation may put finances and credibility at stake, for example, and decisions must be made with limited information about the future (Hadorn et al., 2008)

Leavy (2016, p.9) states that "*Transdisciplinary research follows responsive or iterative methodologies and requires innovation, creativity, and flexibility and often employs participatory research design strategies*." It is the opinion of many researchers that Transdisciplinarity is a specific approach or an innovative way of thinking about research, rather than a specific research method.

In Table 4, Leavy describes the principles of practical transdisciplinarity. She highlights bringing together different knowledge bases, a range of research tools and collaborative teams to find integrated solutions.

Table 4: Principles of Transdisciplinarity (Source: Leavy, 2016)

Principle	Practice
Issue- or Problem-Centered	Problem at center of research determines use of disciplinary resources and guides methodology
Holistic or Synergistic Research Approach	Problem considered holistically through an iterative research process which produces integrated knowledge
Transcendence	Researchers build conceptual frameworks that transcend disciplinary perspectives in order to effectively address the research problem
Emergence	Placing the problem at the center of research (transcending disciplinarity) cultivates the emergence of new conceptual and methodological frameworks
Innovation	Researchers build new conceptual, methodological and theoretical frameworks as needed
Flexibility	Iterative research process requires openness to new ideas and willingness to adapt to new insights

The transdisciplinary process of integrating societal and scientific practice is described in Figure 21. Both the societal and the scientific problems contribute to the problem framing in phase A, from where the problem framing, and teambuilding flows through to phase B where co-creation of solution-oriented transferable knowledge results in phase C. It is here where integration and application of created knowledge are embedded.

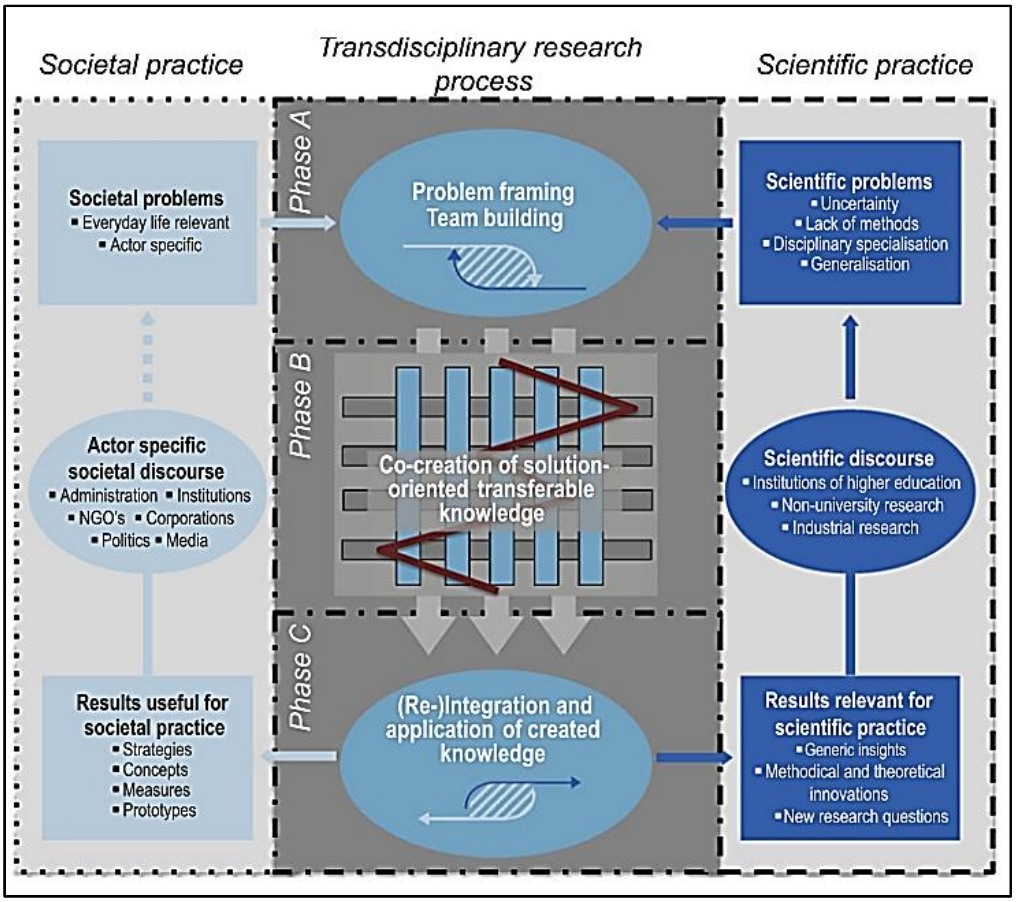

Figure 21: Conceptual model of an ideal-typical TDR process (Source: Lang et al., 2012)

It requires careful consideration of who must be at the table of discussion, how the situation or issue arose, what perspectives of the issue exist, how we would go about gaining a broad and later detailed understanding of a range of aspects

From this, it is clear that TDR is practice-based, it is society centric, and it is focused on change, collective learning and co-creation. There is a clear approach when you compare the Circuits from before, Lang's figure, Leavy and Nicolescu and Cilliers (as well as Hadorn). Clearly, the TDR framework embraces the qualitative and quantitative methods of research and brings powerful approaches to applying those methods to the table.

Esbjorn-Hargens (2010) reflects on Integral Theory introduced by Ken Wilbur (1997) and states that integral means comprehensive - it fits with the deeper philosophical approach of TDR by pointing out the objective and subjective aspects and views that need to be considered in addressing intractable (wicked) problems. In this approach, the different views of infinite realities are focused on the real-world issue at the focal point where Integral Theory exposes and brings into focus the subtleties of the subjective and objective views from the broad stakeholder group (core TDR concepts). The Soft Systems Methodology (SSM) mentioned before, makes the aspects practical through the so-called CATWOE framework, shown below in Table 5.

Table 5: The CATWOE framework of soft systems methodology (Adapted from: Checkland, 2000)

C	Customers	Who are the beneficiaries and how does the issue affect them
A	Actors	Who is involved in the situation
T	Transformation	What is at the transformation that lies at the heart of the system
W	World View	What is the big picture and what are the wider impacts of the issues
O	Owners	Who owns the process or situation being investigated and what role will they play in the solution
E	Environmental constrains	What are the constraints that will impact the solution and its success?

Six practical approaches are used to ensure that the relevant perspectives are considered in building understanding. Both SSM and Integral Theory aim to ensure that social, cultural, technical, and other views are considered.

Combining these methodological and theoretical views, effectively answer the question of who should be at the table of discussion and the question of what should be investigated from an Agri-technical perspective. How does the integration of approaches lead to innovation? The next section will take a closer look.

2.6 Innovation

"*New knowledge creation is nothing more than a relatively high level of meaningful learning accomplished by individuals who have a well-organised knowledge structure in a particular field and also a strong emotional commitment to persist in finding new meanings*" (Orgeron, 2012, p.1). These words, from Blake Orgeron inspired the researcher to persist in finding new meaning.

Innovation is the product of collaboration between many participants of which researchers form one part. The direct result of the interaction between different stakeholders, is what results in innovation. Challenges include the ability to line up different mindsets as well as the capabilities of the people involved and the ability to facilitate sufficient institutional incentives for collaboration (Botha et al., 2014).

Peter Drucker (2002), names seven sources of innovation:

- Unexpected occurrences
- Incongruities
- Process needs
- Industry and market changes
- Demographic changes
- Changes in perception
- New knowledge.

He goes further to emphasise that for innovation to be effective, it needs to be simple and focused.

"*Innovation is not just technology but is rather a comprehensive vision of what the future should look like and which requires changes in many ambits. Innovation is driven by people's needs, ambitions, and dreams, and requires that people at different positions in society change the way they work and live*" (Klerkx, Van Mierlo, & Leeuwis, 2012, p.458).

Innovation studies have a great deal to offer to those who would like to advance the wellbeing of humanity without doing any harm to the environment and subsequent life support systems. Concern for sustainable development provides the ideal backdrop for a broader perspective to innovative thinking (Sachs *et al*., 2010).

Matching the innovation strategy to business goals provides the critical alignment between business objectives and innovation investments and activities. The innovation strategy addresses three questions:

- How much innovation do we need?
- Where do we focus?
- What type of innovation do we need (Davila, Epstein, & Shelton, 2012)?

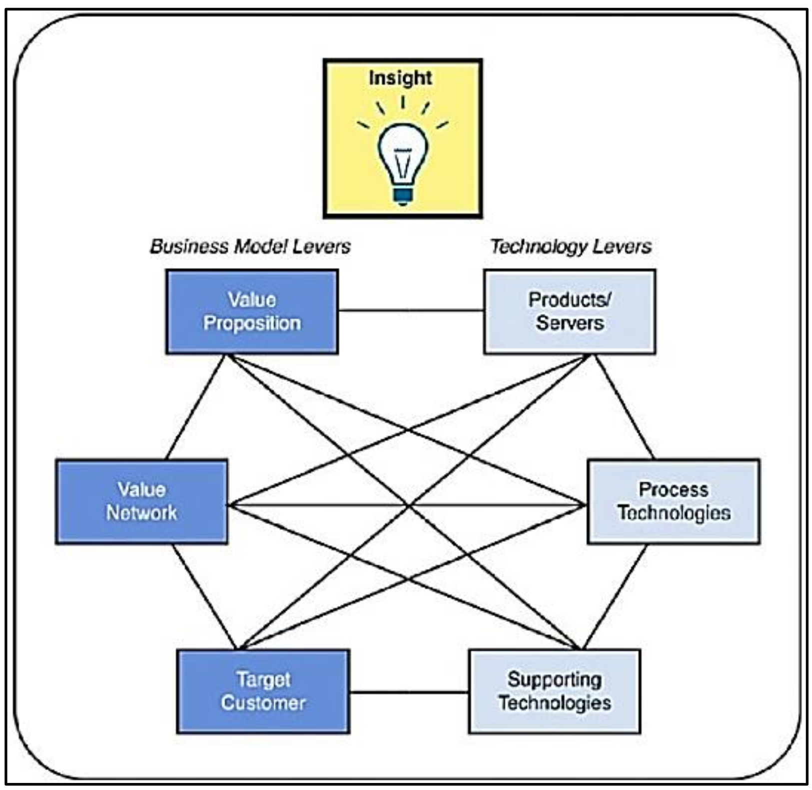

Figure 22: Six levers of innovation (Adapted from: Davila et al., 2012)

Figure 22 illustrates the need for business model levers to work in conjunction with technology levers if new insights are to be achieved.

Botha et al. (2017) are of the opinion that the “Agricultural Innovation Systems” (AIS) approach is an accepted way to understand innovation and organize support for innovation. The AIS approach implies that different stakeholders from academia, industry, the regulatory environment and societal representatives, follow a model of “interactive learning” and “networking” to achieve innovation. The focus here is on the importance of the co-creation of innovation by way of involving a broad range of actors. Furthermore, customers demand greater innovation, near-perfect quality, faster, lower-priced produce with easier access (Kotter, 1995).

2.7 Summary

This chapter introduced the reader to the history and core business of ASW. It positioned the research project within the district of Matamata/Piako and the broader region of Waikato within NZ. This was necessary to connect the project to local influences as far as social, environmental, and the regulatory environment goes. The need to change from the current status quo to a future dispensation was discussed. It was shown that a TDR framework for the research methods would be required to deal with the complexity and diversity of views and that innovation is only possible if the change is deemed inclusive and for the common good.

By dissecting the term ’sustainability’ and by looking at what other regulatory bodies and agricultural businesses are doing in this regard, the researcher delved deeper into the principles and forms of alternative or sustainable agriculture. Understanding the differences between these was vital to continue the chosen path. Eco-agriculture as an “alternative” farming method and soil health as a specific focus area were investigated and fertigation techniques with compost application as a remedy for soil health were identified as a low-hanging fruit for implementation.

Chapter 3: Research Design and Methodology

3.1 Introduction

Because of the complexity of the “wicked” problem, a transdisciplinary framework was needed for the research design as described by Cilliers and Nicolescu (2012). The holistic and integrative nature of transdisciplinarity required the researcher to consider the integral theory model of Ken Wilbur (Figure 23) to split the research into quantitative and qualitative research. The CATWOE framework of soft systems methodology (Checkland, 2000) determined who had to be at the table. Both SSM and Integral Theory had to be taken into account to ensure that social, cultural, technical, and other views were considered. The researcher extracted his methodology for the research from the practical application presented by Leavy in Table 4 and from the conceptual model of an ideal-typical TDR process as described by Bergman et al. (2005). The research design is discussed in Section 3.2.

3.2 Research Design

TDR is holistic and integrated in nature and the integral theory model allowed the researcher to service this need by designing the research into a qualitative and a quantitative part. From Figure 23, it was derived that qualitative research would address the upper left (Psychological and Phenomenological inquiry) and lower left (Cultural and Worldview investigation) quadrants of Wilbur’s model, while the quantitative research was based on the upper right (Behavioural and Physiological analyses) and lower right (Ecological and Social assessments) quadrants.

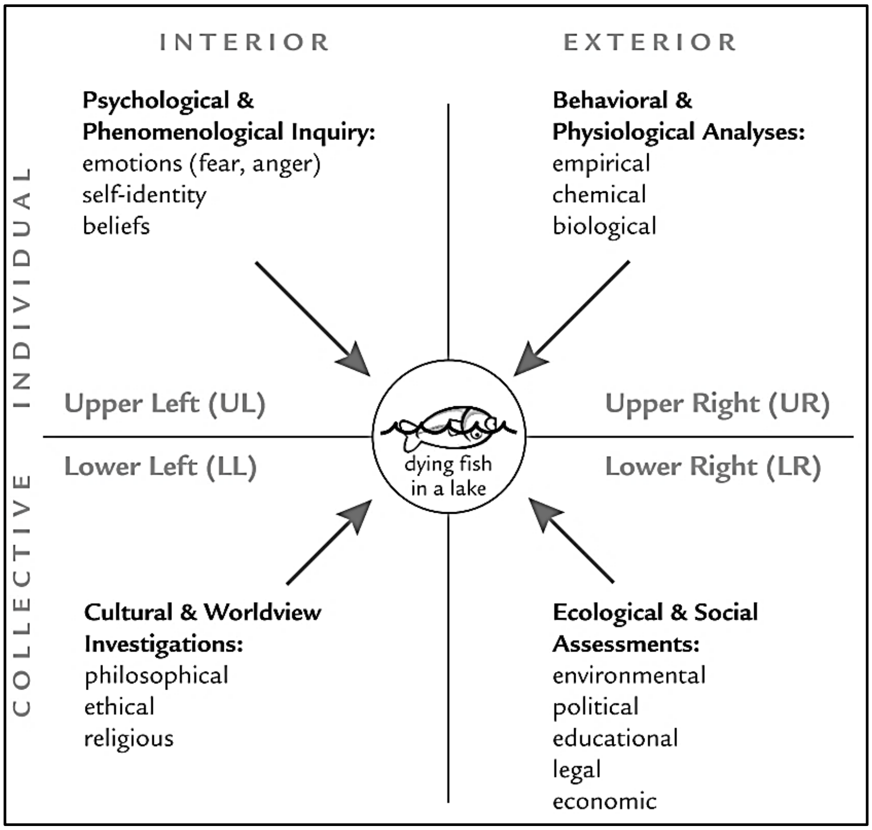

Figure 23: The quadrivium nature of integral theory (Source: Esbjörn-Hargens, 2010)

It was anticipated that a combination of qualitative and quantitative research would be the best design to provide a deeper understanding of the sustainable practices that could steer ASW onto a pathway of effective EA farming.

The planned qualitative research design aimed to facilitate discussion via interviews with key stakeholders in order to facilitate their understanding of sustainability. However, it was important to first understand the nature and profile of ASW as a private company. This involved reviewing the company website and conducting informal interviews with staff (Chapter 2.2.1).

To obtain data to answer the first research objective, interviews with key people who were at ASW during this period, and those who were stakeholders were conducted. This allowed cross-checking and verification of information gathered during the on-farm trial. The results are presented in Chapter 4.

Post interviews, the researcher conducted a thematic analysis that provided for the main themes revealed by interviewees as discussed in the next chapter (4.2.1 and 4.2.2). The quantitative research followed a classical experimental design within a commercial planting of onions irrigated by a centre pivot irrigator. Table 5 indicates the Treatments and their application, while Figure 23 explains the layout of the trial. The detail of the trial design will be addressed in Section 4.3.1.

The research design provides a framework for the collection and analysis of data (Bell et al., 2019). In selecting the appropriate design for this research project, the researcher attempted to fulfil the criteria for business and management research, advocated by Bell et al. (2019, p. 41): "Reliability", "replication" and "validity" aims to search for gaps, suggesting how any gaps might be filled, and considering to what extent the approach remains fit for purpose in a wider context.

This research design will clarify the proposed procedure for the reader in order to gain an understanding of the methodologies applied in Section 3.3 (Kumar, 2011).

3.3 Methodology

To achieve the research objectives (Section 1.3), the researcher followed a mixed-methods research approach. The researcher opted to employ a combination of qualitative (3.4.1) and quantitative (3.4.2) research methods in order to analyse the research statement (Creswell & Clark, 2017). Together, these two methods provided for reliable and valid measurable conclusions (Sattar, Wang, Muqadas, Ashraf, & Tahir, 2017).

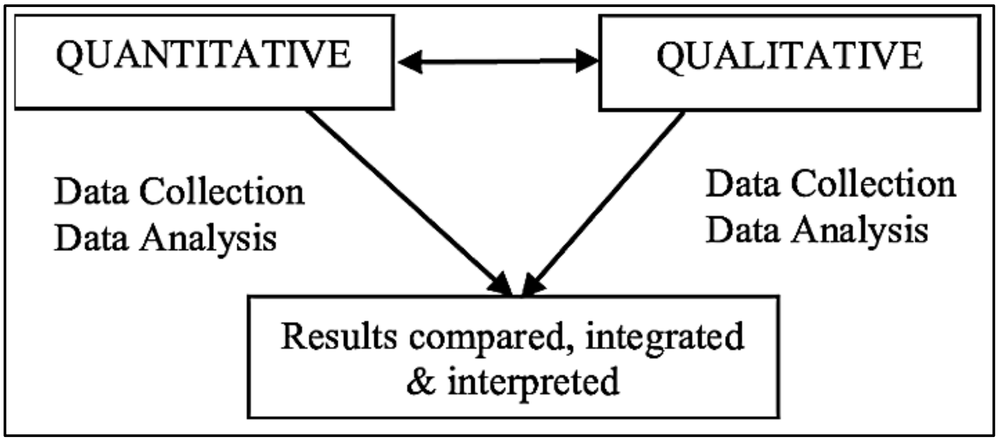

Figure 24: A Visual Diagram of the Mixed-Methods Concurrent Triangulation Strategy (Source: Atif, Richards, & Bilgin, 2013)

The researcher used this approach to answer a broad and more complete range of research questions. Integrating (triangulation) qualitative and quantitative approaches overcame the weaknesses and utilised the strengths of each approach. By applying the mixed-methods approach, insights into and understanding of the data were improved. Integrating qualitative and quantitative data provided strong evidence for conclusions and triangulation of the data from the different methods and increased the validity of the results and the conclusions (Figure 24).

The on-farm trial followed a participatory research methodology to enable ASW within their own environment to improve their production practices, systems and processes. The rationale for the latter methodology is to allow for ASW to develop sustainable solutions for their business after considering the research recommendations (Section 5.5) It is important to note that the researcher was attached to ASW as a production manager for the most part of the study. Working within the Growing team, for the duration of this study, the researcher had access and exposure to the people and systems at ASW.

3.4 Data Collection and Research Instruments

The researcher collected his data through semi-structured interviews (qualitative research) and an on-farm trial (quantitative research). Collection and analysis of qualitative data in the first phase were followed by the collection and analysis of quantitative data that build on the results of the first phase.

Other means of data collection were informal discussions with co-workers, industry partners and stakeholders. Prominence was given to the collaborative nature of the study. Photographs, documents, internal company material and numerous other sources of information were used as part of data collection. Personal discussions between the researcher, management, and academic institutions contributed to the inclusive nature of the study.

A narrative literature review (Alan & Bell, 2011, p. 101) was used to analyse trends and to reflect on opinions of role players about the study. The company was introduced to the reader as an affected party. Its local and regional position with influences were defined. The need and the process of change were debated after which sustainability as a concept in general, eco-agriculture in specific and soil health as a focus area were explained.

The transdisciplinary approach and framework were discussed as a vessel of achieving innovation for ASW. The collecting of data mentioned was followed by qualitative (Section 3.4.1) and quantitative (Section 3.4.2) research instruments.

3.4.1 Qualitative Research

It was anticipated that a qualitative research design would be an appropriate methodology to provide a deeper understanding of the sustainable practices that could steer ASW onto a pathway of effective eco-agricultural farming.

The planned participatory and collaborative research enquiry design aimed to facilitate discussion via semi-structured interviews (hereafter referred to as interviews). The mentioned design is based on the principle of exploring gaps relating to sustainable farming practices and utilizing the key people and stakeholder's knowledge contribution in order to maximize research findings and outcomes.

It is assumed that a participatory and collaborative approach will increase the possibility of the agricultural community accepting the research finding and outcomes and as a result demonstrate preparedness and involvement in solving the problems and issues confronting sustainable agricultural practices (Kumar, 2011). Essentially, the interview design allows for interviewees to share knowledge and experiences pertaining to sustainability with little interference by the interviewer. The researcher chose not to follow a structured interview approach as it was envisaged that such an approach would be imprudent as it may lead the interviewer to talk about what the interviewer wants the interviewee to talk about (Sarantakos, 2012).

Correspondingly, semi-structured interviews were used because this research explicitly explores interviewees' perspectives on sustainability within an agricultural context rather than a broad perspective on sustainability. Given the landscape of conceptual and intellectual debates, practical concerns, and increasing legislative consideration, it is important to continually and critically appraise the sustainability concept.

The selection criteria for the interviewees', targeted expert stakeholders within the Waikato sustainability community. A purposive convenience sample of interviewees was employed based on their involvement within the areas of sustainable agriculture. Purposive sampling forms part of the qualitative research design in that it promotes a depth of understanding and interpreting current views pertaining to sustainability (Etikan, Musa, & Alkassim, 2016).

To obtain data to answer the first research objective (Section 1.3), interviews with key people - who had been in management positions at ASW during this period and those who were stakeholders- (explained above) were conducted.

This allowed cross-checking and verification of information gathered during the on-farm trial of which the results are presented in Chapter 4. To be inclusive of the triple bottom line (People, Planet and Profit) requirements for sustainability (Section 1.3 to 1.7) in regards to the environmental, economic and social terms as described by Alhaddi (2015) inputs from people representing those three areas were selected to a), gather insights into their perception of sustainability and to b), do a SWOT analysis with them.

Table 6 illustrates the interviewee identifier, the dates on which the interviews took place, and the sector the interviewee represents. A description of their specific roles is listed as footnotes. The research opted to utilise a Strengths-Weaknesses-Opportunities-Threats (SWOT) type analysis in order to discover interviewees interpretation and perceptions of sustainability.

The intended SWOT analysis aims to explore the potential benefits of embarking on a sustainability road for ASW. Also, to search for options, that eventually will lead to change being implemented in a commercial vegetable farming operation. The use of the SWOT analysis may facilitate the development of strategies that might overcome existing or future challenges to the sustainability concepts (Bull et al., 2016).

Table 6: Participants in the interview process, the date of the interview and the interviewee's current sector.

Interviewee identifier	Date of interview	Sector
KB	19 March 2019	Marketing[1]
CEO	27 March 2019	Business Owner[2]
CFO	05 March 2019	Finances[3]
HR	05 March 2019	Human Resources[4]
PM	26 March 2019	Growing Team[5]
JA	09 April 2019	Industry Partner[6]
AH	14 March 2019	Research Institution[7]
AT	08 April 2019	Regulatory Environment[8]
Mayor	28 May 2019	Political District[9]
JS	28 May 2019	District Representative[10]
PM	14 May 2019	Political Regional[11]
Landowner	04 June 2019	Local Landowner[12]

3.4.2 Quantitative Research

The quantitative research focused on an on-farm trial to demonstrate the practical implementation of some of the eco-agricultural principles, identified in Chapter 2, needed to establish a thriving "sustainable" business for ASW.

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[1] General Manager of the marketing export business of ASW.
[2] Chief Executive Officer of ASW responsible for strategic direction and running of the company.
[3] Chief Financial Officer responsible for the financial management within ASW.
[4] Human Resource Manager responsible for the social wellbeing of ASW employees.
[5] Production Manager managing the Growing team in Pukekohe.
[6] Industry partner supplying contracting services to ASW.
[7] Senior researcher based on the North Island of New Zeeland associated with the Federation for Arable Research.
[8] Member of the Waikato Regional Council.
[9] Mayor for Matamata/Piako District 2018/2019.
[10] Council member for Matamata/Piako District and researcher for AgResearch.
[11] Member of Parliament for the Waikato Region of New Zealand.
[12] Landowner leasing property to ASW in the Matamata District

The main reasons the researcher decided to use a quantitative research approach were:

- The results obtained from the research builds accurate and reliable measurements that allow for statistical analysis.
- The on-farm trial in this study can be summarised, compared and generalised.
- On-farm trial will back-up claims about the use of sustainable farming practices.
- On-farm trial will demonstrate return on investment.
- Provide a method to make data accessible to the farm owners and general Waikato agriculture community.
- Provide evidence of success and highlight sustainability gaps.

Onion Fertigation Trial

Fertigation by itself is not new, but within ASW, and within the New Zealand onion industry, fertigating onions are not a common practice. This trial had to be approved by the business, and by-in from co-workers were necessary. This research project required co-creation and collaborative and collective learning.

Aim

a. To investigate whether fertigation is advantageous in comparison to a standard side dressing programme in terms of yield, quality and input cost.
b. To demonstrate the advantage of adding compost to paddocks prior to onion crop establishment.

The trial was conducted from August 2018 to February 2019 at the Shatin farm of ASW in the Matamata district of the Waikato region of NZ (co-ordinates 37°50’46.5” South and 175°46’38.10” East) with an elevation of 72 meter.

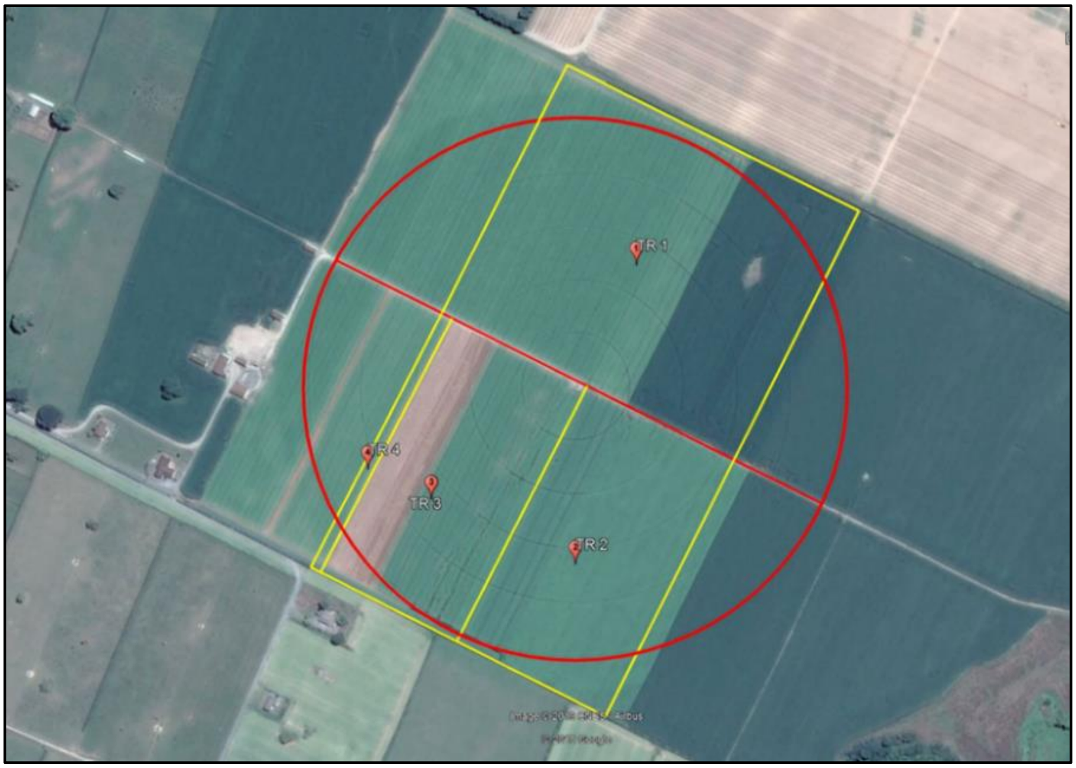


Figure 25: Onion Fertigation trial layout at Shatin Farm, Matamata (Source: Google Earth, 2019)

A 36-hectare area under centre pivot irrigation, located on the farm Shatin, was divided into four treatments (Figure 25). The same variety of onions was planted in all the treatments. In Table 7, the treatments and their respective fertilizer regimes are shown.

Table 7: The table below describes the different treatments for the Onion Fertigation Trial.

Treatment number	Fertilizer regime
T 1	Fertigation
T 2	Fertigation + compost
T 3	Standard fertiliser + compost
T 4	Standard fertiliser

Package work breakdown

As this trial was conducted in a commercial vegetable farming operation, the business had to continue its daily functions. The researcher had to mould his research around the operational capabilities and responsibilities. It was necessary to package the breakdown to get buy-in from the business.

Required resources

- Waterforce® supplied the dosing pump and the mixing tank.
- ASW supplied the solution tank and execute the trial.
- King Electric did the electrical work.
- Fruitfed® supplied fertilizer products and helped to develop the software program.
- Daltons® supplied the compost.
- ASW staff did production tasks and evaluated the trail.
- Waikato Regional Council issued the consents for irrigation.

Associated cost

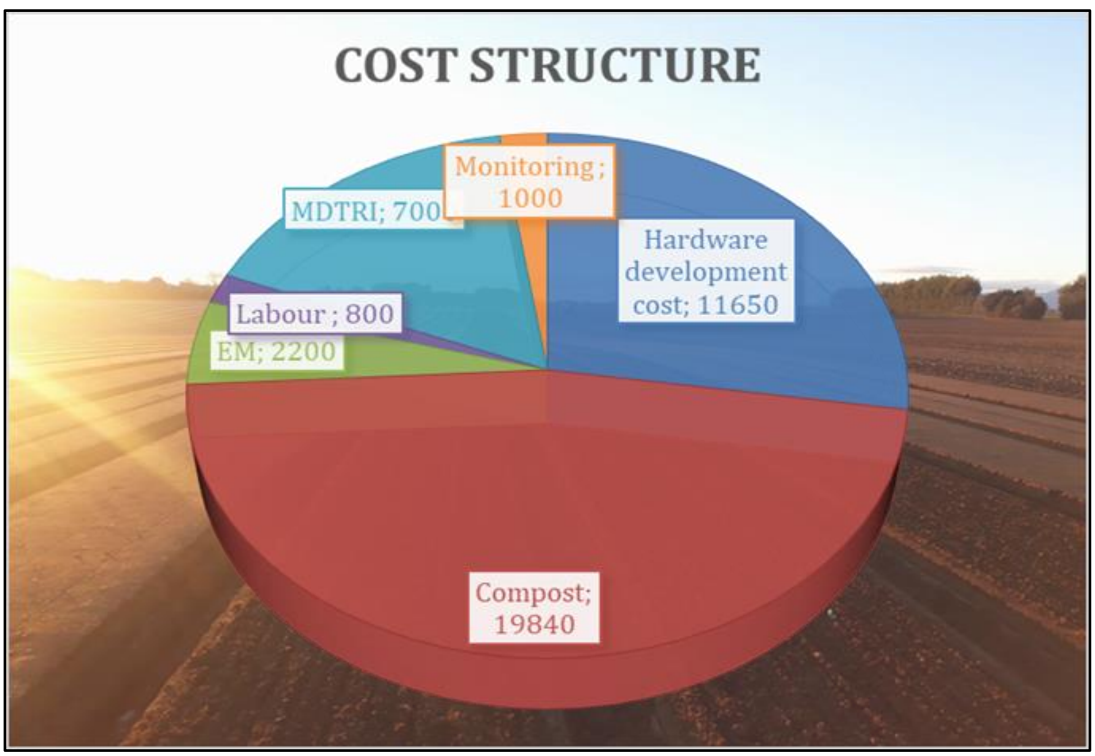


Figure 26: Cost structure of the Onion Fertigation Trial.

It was inevitable that costs would be incurred to execute this research project. These costs reflect the expenditure on the Onion Fertigation Trial, only (Figure 26). The cost structure for the fertigation trial, considering the additional costs, is shown in Table 8. The additional cost was considered to be the study fees for the master's degree.

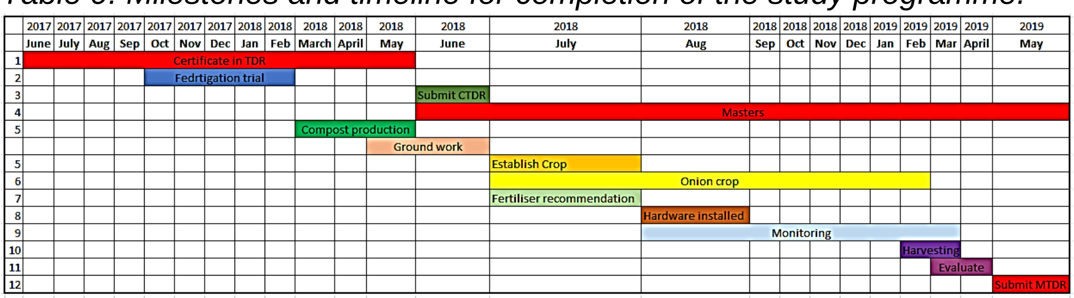
Table 8: Cost structure of the Onion Fertigation Trial considering the additional costs.

Item	Operational expenses	Additional
Fertigation Hardware[13]	$11650	0
Compost[14]	$19840	0
EM	$2200	0
Labour	$800	0
MDTRI fees[15]	0	$7000
Monitoring cost	0	$1000
Contingencies	$1510	0
Total cost	**$47000**	**$8000**

Milestones and timelines for the project

The milestones and timeline reflected here includes the certificate (Post Graduate Certificate in Transdisciplinary Research) part of the studies. The study commenced in June 2017 with the Certificate part and will conclude with submission of the master's degree studies in May 2019 (Table 9).

Table 9: Milestones and timeline for completion of the study programme.



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[13] The hardware required consisted of a dosing pump, mixing pump, stock holding tank and a mixing tank. Costs included plumbing and electrical works.

[14] Compost applied at $20m^3/ha$

[15] Fees reflected as additional are for the master's degree.

Estimated running costs

The running costs of this trial were not considered as the trial were conducted in a commercial planting of onions and the running costs that could be allocated to the trial only, were insignificant.

Risk quantification and management

In this section initial risks are identified.

- Legal
    - Waikato Clean Rivers Initiative (Waikato Regional Council, 2018).
    - Regional council consent for water take and usage, will have to be applied for, to cater for the irrigation needs outside of the existing consent.
    - Global Gap accreditation standards will have to be adhered to.
- Ethical

    All codes of professional ethics embody three main components:

    1 Standards of professional competence

    2 Standards of professional integrity

    3 Accepted professional procedures (Downie, 1980).
- Cultural
    - A low risk is associated with the immediate cultural environment.
    - The culture within the organization will be affected as new production practices are rolled out.
- Political
    - Tax on Irrigation water
    - Export requirements and trade agreements.
- Technical
    - There is a risk associated with developing the fertigation hardware as far as period, and financial overspend. Rigorous project management controls will mitigate these risks.

  - Developing the fertilizer recommendation software must be completed on schedule to cater for optimal establishment of the crop.
  - The risks associated with resourcing the inputs relate to availability and possible import restrictions. By ordering the products well in advance, this risk could be managed effectively.

Intervention and methods

The process consisted of:

- Develop and install a fertigation unit with the existing center pivot irrigator to deliver fertilizers and other agents through the water to an onion crop.
- Introduce compost to the onion production system.

Communication and stakeholder engagement plan

This research project was a co-creation effort which entailed good communication between all stakeholders. Regular meetings with specific industry partners took place and feedback was given. The success of this project depended on an open communication channel and co-creation. The research proposal complied with the format prescribed and was subjected to approval by both the academic partner (Wintec), as well as the industry partner (ASW).

Stakeholders

The stakeholders who were part of this collaborative are listed in Table 10. In following the TDR framework, the researcher involved stakeholders from industry, research institutions, academia, and the regulatory environment.

Table 10: Listing the Institution/entity involved and their respected roles in the research on Onion Fertigation.

Institution/entity	Partnership role
AgResearch	Research institution
ASW	Industry partner
Daltons	Compost producer
EMNZ	Biological inputs supplier
Enza Zaden	Seed supplier
King Electrical	Electrical works
Matamata/Piako Community	Societal influencer
Matamata/Piako District Council	Regulatory partner
Paul and Dave O'Sullivan.	Landowners
Rivulis Australia/ New Zealand	Irrigation equipment supplier
Syngenta	Agro-chemical supplier
Waikato Regional Council	Consent authority
Waterforce	Fertigation unit developer
Whealleans	Fertilizer spreading contractor
Wintec	Academic institution

Quality plan

Each phase was assessed, and feedback given to the developer. Continuous improvement was encouraged throughout the project, and time was allowed for adjustments and fine-tuning. The quality of work was subjected to relevant industry standards like Global Gap, ISO 9000, and others where relevant. Contractors and collaborators were held accountable to deliver on a quality project.

3.5 Ethical Procedure

Before conducting the interviews, ethical approval had to be obtained from Wintec. The researcher prepared a Participant Information Sheet (Appendix A) which were lodged with the Human Ethics in Research group at Wintec for approval. After ethics approval was granted (Appendix B), the researcher forwarded all the relevant documentation, which also included a Summary of Discussion Themes (Appendix C), to all the interviewees.

The interviewees completed and signed a Participant Consent Form (Appendix D) and returned the said form to the researcher. After completion of the interviews, each recorded voice file was transcribed, and the transcription presented to the interviewee for editing and approval. These transcriptions will be submitted separately to Wintec as part of the thesis.

This project will adhere to all ethical requirements. The TDR approach to ethics can be summarized in saying that people must take responsibility for decision and action in every level of addressing issues.

3.6 Broad Requirement and Needs Statement

Access to land, commercial onion crop establishment, a centre pivot irrigator, irrigation water availability, labour, organic and in-organic fertilizer inputs, hardware to fertigate biological and inorganic fertilizers, a software program to calculate the fertigation recommendation, quality compost prepared to specification and needs.

Time and access to relevant stakeholders to complete the interview process. The researcher used the Otter software program to transcribe the voice files which he recorded on his mobile phone.

3.7 Conceptual Value Proposition

By interviewing relevant stakeholders, broad insights will be gained into what the perceived understanding of and the potential value for the business of a sustainability model could be.

A strengths-weaknesses-opportunities-threats (SWOT) analysis undertaken with the interviewees will potentially identify strengths, weaknesses, opportunities and threats for the business, preparing them strategically to be a thriving enterprise.

The on-farm trial will test the low hanging fruits of a sustainability model under local climatic conditions and with ASW management styles.

Innovation in the form of a fertigation unit will be implemented together with a tailor-made software program to manage the fertigation recommendation. Liquid fertilizer options will be explored in collaboration with the industry to facilitate the application and logistical process involved.

Additional land for cultivation will become available due to the public's perception of EA practices as a "Green and sustainable farming" system which improves soil health, supports ecology, and ultimately raises the land value.

The marketing benefit of sustainability and the philosophy of EA could lead to a premium price being paid for the company's products which would lead to higher productivity of resources and would enable the company to afford higher lease prices for land.

The researcher proposes that the concept of EA could hold great value for the benefit of ASW and that the development of the deliverables will lead to the customization of the baseline principles for innovation opportunities within this philosophy.

3.8 Chapter Summary

Chapter 3 explained the reasoning for the research design and the chosen methodologies. Various methods of data collection were introduced, and the nature of the qualitative and the detail of the quantitative research was discussed and debated.

The ethical procedure was clarified where after a broad requirement and needs statement for the onion fertigation trial was formulated. This was followed by a discussion of the conceptual value proposition. The aim of Chapter 3 was to enable future research into the subject to be replicated accurately. In Chapter 4, the findings and discussions of the research are offered.

Chapter 4: Findings and Discussions

4.1 Introduction

This chapter outlines the data collected from semi-structured interviews conducted with 12 participants relating to their interpretation and views on research Objective 1 (Section 1.3).

Through thematic analysis, the following representative themes emerged: Perceptions of sustainability (Section 4.2.1) and results of a SWOT analysis (Section 4.2.2).

Data collected from the onion fertigation trial revealed the research results pertaining to Objective 2 (Section 1.3) and was discussed in Section 4.3. The chapter concludes with a summary in Section 4.4.

4.2 Qualitative Research

At the start of the interviews, participants were asked to reflect on the question: how we might embed sustainable agricultural principles in a Waikato based, commercial vegetable farming operation, in such a way that it will ensure a thriving business for the future.

When reflecting on the above-mentioned question, interviewees identified the following sub-themes crucial to sustainability:

4.2.1 Interviewees’ Understanding of the Concept of Sustainability

Table 11: Highlighted themes with the number of times mentioned and supportive literature derived from the interviews.

Sustainability theme	**Number of times mentioned**	**Supportive literature**
Planet/ Environment	7	(Mann & Schäfer, 2018)
People/ Social	6	(Buttel, 1990)
Soil health	6	(Reeve et al., 2016)
Ongoing/ Long term	6	(Gliessman, 2014)
Profit/ Financial	5	(Pigford, Hickey, & Klerkx, 2018)

At the start of this research, the researcher had assumed that sustainability entails environmental, social and financial aspects. Interviewees’ feedback aligns with the researcher’s pre-research assumptions in the following way:

Participants’ feedback portrayed in Table 11 highlighted Planet (environment) as the dominant sub-theme relating to sustainability.

> “Sustainability is about the environment and the ability to maintain a more closed eco-system or continuous eco-system where it has the capability to continue to sustain itself” (KB, interview, 19 March 2019).

Furthermore, participants maintained a broad consensus that soil-health was an integral part of sustainability.

> “Sustainability is how we can improve and protect our soils to better them” (PM, interview, 14 May 2019).

People (social) and ongoing/long term is equally important sub-themes.

> “Sustainability is about having a place where people thrive and work well” (JA, interview, 09 April 2019).

> “My wife and I went to Germany, and we stayed on a vineyard that had been growing grapes for 980 years, that is sustainability to me” (AH, interview, 14 March 2019).

Profit (financial) surfaced as an important sub-theme but, not as substantial as the latter mentioned sub-themes.

> “Sustainability is about the social, the ecological and the financial point of view” (CEO, interview, 27 March 2019).

It is evident from Table 11 that the topics of People, Planet and Profit is well supported by the interviewees. A holistic approach to sustainability and the need to achieve societal, environmental as well as financial sustainability, were mentioned by the interviewees. The importance of soil health is also central to the perception of sustainability. The identified theme of soil health could be paramount to the implementation of sustainable practises for ASW.

4.2.2 SWOT Analysis

Interviewees were familiar with the purpose and usefulness of a SWOT analysis. Data collected regarding the current and potential strengths of employing a sustainability framework within the ASW business operation are portrayed below:

4.2.2.1 Strengths

Interviewee feedback on the strengths associated with sustainability helped the researcher to identify the themes necessary to maintain ASW’s current niche in the agricultural marketplace/community.

The strengths identified by the interviewees are highlighted in Table 12.

Table 12: Strengths identified and mention by:

"Strengths" themes	**Mentioned by:**
New Zealand's clean green image	KB
The flexibility of the ASW	PM
Differentiating themselves (ASW)	CFO
Managing soil responsibly	PM
Community involvement	Mayor
Utilising cover crops	AH
Economy of scale	JA

It was clear from the feedback received from the interviewees that ASW has already differentiated themselves from their competitors and that they have a good standing in the community. Their ability to differentiate themselves and to execute tasks were mentioned.

Reflecting on these results prompted the researcher to consider what changes ASW need to implement and what trends ASW should be aware of. The impact of these considerations will be discussed in Chapter 5 and presented as recommendations that should lead to sustainable farming.

4.2.2.2 Weaknesses

Participants' views on perceived weaknesses compelled the researcher to acknowledge some realities that impact on ASW's sustainability. As potential weaknesses, the participants named these issues:

The weaknesses are listed in Table 13.

Table 13: Summary of weaknesses and mentioned by:

“Weaknesses” themes	**Mentioned by:**
Land ownership models	JA
Profitability and financial resources	CEO, PM, CFO
Attracting young talent	MP
Conflict with communities	Mayor
Managing data	AH
Commodity based products	KB
Consumer resistance	CFO

The CEO, PM and CFO have mentioned the financial implications of a sustainability model. It is a contentious issue. The need to manage data effectively is a weakness identified by the research institution. The current ASW land ownership model of leasing land on the short term was also perceived as a weakness.

4.2.2.3 Opportunities

The potential opportunities, according to the participants, are numerous. The following opportunities for ASW were mentioned when discussing the sustainability pathway with the interviewees.

A summary of the mentioned opportunities follows in Table 14.

Table 14: Summary of opportunities and mentioned by:

"Opportunity" themes	**Mentioned by**
New markets	KB
Feeding the population	AT
Community involvement	Mayor
New technology	MP
Influence policy	MP
Build on New Zealand's clean green image	KB
Attracting people	JB

Engaging with the community and especially working with schools were mentioned by more than one participant. The opportunity to develop new and alternative markets were also prominent in the discussions. Precision farming and technological advancements were identified. Various opportunities for environmental improvements were raised.

4.2.2.4 Threats

During the interview, participants listed the identified threats which they associated with a drive for ASW to be more sustainable. They also mentioned threats associated with ASW not becoming more sustainable. These identified threats have been summarised into Threat themes, shown here in Table 15.

Table 15: Threat themes identified by the participants, the number of times they were mentioned and supportive literature.

"Threats" themes	**Number of times mentioned**	**Supportive literature**
Financial aspects	7	(Greenhalgh, Samarasinghe, Curran-Cournane, Wright, & Brown, 2017)
Soil	7	(Brussaard, De Ruiter, & Brown, 2007)
Regulatory changes	6	(WaikatoRegionalCouncil, 2018)
Land	5	(Chappell & LaValle, 2011)
Reduced yields	3	(Malherbe & Marais, 2015)
Agro chemicals	2	(Scherr & McNeely, 2008)
Cover crops	2	(Malcolm et al., 2018)
Dust pollution	2	(McCrea, 1990)
Markets	2	(Hatt et al., 2016)

It is apparent from this summary that "financial" sustainability is perceived as a significant threat for the participants. The fear of reduced yields as a result of an implementation of sustainable principles were mentioned by three participants and this relates to financial sustainability. Issues related to soil and sediment control also featured prominently. Changes to the regulatory and or political environment were also listed. Of significance to this study is the identification of land ownership and custodianship as a perceived threat.

During the interviews, general observations and discussion points were raised, which justify mentioning here.

4.2.3 General Comments

To be “sustainable” is no longer a differentiating factor, customers expect businesses to be sustainable in what they do and ASW will have to discover a more powerful differentiator.

- “Our customers expect sustainability to be part of any businesses approach anyway” (KB, interview, 19 March 2019).
- “If you said all our produce was grown pesticide or insect or herbicides free, that's a point of difference” (PM, interview, 26 March 2019).

A “sustainable brand” would be diluted because of the marketing model where ASW has no visual presence in the export market.

- “SoFresh, for example, is a business brand, no consumer in the world would know what that means” (KB, interview, 19 March 2019).

Financial resources, but also human resources, will have to be allocated to a sustainability drive.

- “Successful implementation will only happen if we have enough resources and dedication and focus on doing it” (KB, interview, 19 March 2019).
- “You can’t look after your people or your planet unless you financially can do so” (JA, interview, 09 April 2019).
- “It's got to be able to meet the economic outputs of that business” (AT, interview, 08 April 2019).
- “Trials or any piece of work can fail as you have to carry it through to gross margin” (AH, interview, 14 March 2019).

Root crops are not eaten fresh and would therefore not have the same impact on consumers if they were to be organically grown.

- “I'm not sure what the market would be for root vegetables grown organically” (CFO, interview, 05 March 2019).

The dilution of the brand name selling into supermarkets is highlighted.

- "You will be selling the same product as your competitors, because you've got your supermarket selling no-name brands" (CEO, interview, 27 March 2019).

Sustainability would not have an effect on the number of people ASW would have to employ. This is correlated to the usage of manual labour instead of agro-chemical applications for weeding crops.

- "I don't think we'd employee more people if we become more sustainable" (HR, interview, 05 March 2019).

Effective communication internally and externally as well as by-in from staff were emphasised.

- "We will have to spend some time talking to all of the staff about what sustainability means" (HR, interview, 05 March 2019).
- "ASW will need to convince the general public that their products are grown in a sustainable manner" (HR, interview, 05 March 2019).
- "You need to have a mindset change that is focused on wanting to move in this direction" (PM, interview, 26 March 2019).
- "That really needs to be pushed by our leaders" (PM, interview, 26 March 2019).
- "You need to do your homework and research before you jump into it (PM, interview, 26 March 2019).
- "You need to know exactly where you want to go" (PM, interview, 26 March 2019).

Soil health, and the importance of looking after the soil, was key to the discussion.

- "We must not cultivate our soils as much and we have to get the biological life going" (JA, interview, 09 April 2019).
- "We can't have our soils eroding into rivers and streams" (JA, interview, 09 April 2019).

- “We tried some radish and we were trying clover and trying ryegrass but like everything it must be economical” (JA, interview, 09 April 2019).
- “I think groundwork is a critical thing” (AH, interview, 14 March 2019).
- “Crop rotation is really important” (AH, interview, 14 March 2019).
- “Trying to choose chemistry that will have less impact on the organisms in the soil is important” (AH, interview, 14 March 2019).
- “Be very aware of the soil moisture content when you cultivate” (AH, interview, 14 March 2019).

4.2.4 Strategic Opportunities

This section will not be included for public access and will be under embargo. It contains strategic initiatives which might be subjected to commercial sensitivity.

4.3 Quantitative Research

An on-farm trial was initiated to evaluate the practicality and efficacy of onion fertigation and the usage of compost as part of the eco-agricultural practices identified in the literature review. It was necessary to conduct this trial under local climatic conditions and with current manager inputs to determine the feasibility of the implementation of the initiatives into the broader ASW business.

4.3.1 Research Findings: Onion Fertigation Trial

4.3.1.1 Introduction

Objective 2 of this study was to investigate the potential for successful implementation of sustainable agricultural production practices in support of soil health and plant health improvements by evaluating if fertigation techniques and compost applications are advantageous in comparison to a standard fertilizer programme in terms of yield, quality and financial results.

Fertigation systems allow the Grower the flexibility to revert to spreading granular fertilisers if weather conditions dictate. Because fertilisers are delivered to the root system of plants through the irrigation equipment, it is vital that the said equipment be maintained and calibrated to deliver on this promise effectively. The guidelines of Irrigation New Zealand (Irrigation New Zealand, 2013) were used to calibrate the centre pivot system before planting commenced (Figure 27).

Figure 27: Calibrating the centre pivot irrigator according to the Smart Irrigation guidelines.

4.3.1.2 Materials and Methodology

Planting and agronomic practises

Groundwork: After the previous crop of onions, the ground was left fallow. It was then worked up with a Simba implement and power harrowed to a fine tilth.

Figure 28: Preparing ground and planting onions at ASW in Matamata.

Soil Type: The soil type at the trial site was classified as Ngakura-9a.1 (Appendix E). This soil type is described as a deep (>1 m), loam over sandy soil with unlimited root depth. It is stone less with a clay range of 20-25% and is well-drained. The dry bulk density of the topsoil is 0.78 g/cm^2.

Previous crop: *Allium cepa* (Onions)

Onions planted: The onions were planted on the 13th and 21st of August 2018 with an Agricola three bed precision vacuum planter (Figure 28).

Variety:	The red onion variety: Rubillion.
Seeding rate:	630 000 seeds/hectare
Seed treatment:	The seeds were coated by Seeds and Field and treated with 0.55% Mesurol® and 2% Pro Guard®. The germination rate was 95%.
Lifting:	Onions were undercut (lifted) with a Samon onion lifter and windrowed on 29 January 2019.
Harvested:	The onions were harvested on the 13th and 14th of February 2019 with a Shucknecht self-propelled harvester.
Fertilisers:	The relevant treatments received granular fertilisers broadcasted with an Amazone fertiliser spreader and the fertigation were dosed into the irrigation system with a Grundfos fertigation pump. Compost at a rate of 20 m^3 per hectare was broadcasted before planting by Whealleans contractors and power harrowed into the soil on Treatment 2 and 3.
Irrigation:	The crop was irrigated using a Valley® Centre Pivot irrigator and all treatments received the same irrigation. Irrigation were scheduled calculating the evapotranspiration, considering the crop factor, using the check book method and by monitoring soil moisture with a neutron probe.

4.3.1.3 Measurements

Chemical soil analysis

Soil samples were taken at the following intervals:

a. Pre-base fertiliser application

b. Post-base fertiliser application at the time of planting

c. Post-harvest

Within each treatment, 20 cores of soil were collected using a standard soil auger at a depth of 150 mm. Samples were collected walking in a "W" pattern through each treatment covering the whole area. These were then combined and mixed up into a 1 kg sample plastic bag supplied by the laboratory. The samples were kept refrigerated until delivered to the laboratory the following day (Hill Laboratories Limited, 2019b).

Soil texture analysis

Soil samples were collected for texture analysis from each treatment. Five plots were randomly selected for sampling within each treatment. A hole was dug at each plot site to a depth of 450 mm. Soil was collected from this hole at 150 mm, 300 mm and 450 mm respectively using a spade and a ruler. The soil from the five sites was then combined and mixed up to represent one sample of 0.5 kg for each treatment. The soil was placed in a plastic bag and refrigerated until delivered to the Eurofins laboratory in Auckland (Eurofins, 2018).

Soil biology analysis

All soil biology analyses were performed by the Soil Foodweb Institute of New Zealand (SFISA) laboratory located in Waihi, NZ. Several representative soil samples were collected as per the chemical analysis protocol to a depth of 150 mm. The samples were then combined and mixed up into one plastic bag of 0.5 kg. The soil samples were refrigerated until delivered to the (SFINZ) laboratory in Waihi within 48 hours (Soil Foodweb NZ, 2016).

Compost analysis

The compost used in the trial was produced by Daltons™, a commercial enterprise in Matamata. Several small 'grab samples' from the bulk compost batch were collected and then combined into one composite sample of approximately one kg and store it in a stout, sealed plastic bag. Samples were taken prior to application and sent for chemical analysis to Hills Laboratories in Hamilton (Hill Laboratories Limited, 2019a).

Drone mapping

Drone mapping was done by the researcher using his own DJI Phantom 4 drone. Map sets were produced using the DroneDeploy software package installed on a mobile phone and then uploaded to the DroneDeploy website for processing (DroneDeploy, 2019).

Weather data

Weather data was collected from a Davis, Vantage Pro2, weather station situated at the offices of ASW in Matamata. The weather data was representative and equal for all the treatments. Data collection and averaging procedure: Days with less than 18 hours of valid data were not included in the ET, Solar Energy, and Wind Run total or average calculations. All included days with less than 24 hours of data were treated as fractional days. Irrigation totals and averages were not affected by missing weather data and were computed for the entire reporting period. The evapotranspiration and heat degree days were calculated using the Agricultural Management Module (Davis Instuments, 2019).

Rainfall and Irrigation

Rainfall was measured at the trial site using a standard rain gauge. The measurements were done on a weekly basis and recorded in an Excel™ spreadsheet. Irrigation data was logged after each event against the date of application, amount of water (mm) applied, time of application and duration of application (hours). A National Institute of Water and Atmospheric Research

(NIWA) weather station on the ASW farm at Matamata was used for data collection and reporting on seasonal trends.

Soil Moisture

HydroServices measured the soil moisture with a neutron probe to determine irrigation requirements. These direct measurements removed any assumptions and doubts associated with evapotranspiration models. Three aluminium access tubes of 800 mm length respectively were installed into the soil at key locations within each treatment.

Three locations were used to get an average spread over the onion beds and the spray track. Soil moisture was measured weekly at 0-200 mm, 200-300 mm, 300-400 mm, 400-500 mm, 500-600 mm and 600-800 mm depths respectively. The readings from the tubes were averaged to provide an accurate assessment of the soil moisture content in the field or crop. This allowed an irrigation management programme to be developed in consultation with the grower. Data was downloaded and refined using the Probes for Windows software program and then downloaded into an Excel™ spreadsheet and graphs generated (Hydro Services, 2019).

Dry leaf analysis

Onion leaf samples were collected from the different treatments and sent to Hill for chemical analysis on 03 January 2019. Within each treatment, leaves were collected from the same area where the yield assessments were done. Thirty, of the youngest matured onions’ leaves, were randomly selected, placed in a plastic bag and kept refrigerated until sent for analysis as per the Hill Crop Guide for Onions. (Hill Laboratories Limited, 2019b).

Root analysis

Five plants from each treatment were hand-harvested taking care to recover as many of the roots as possible. The plants were dug using a spade. The roots were cut at the base of the plant, keeping them intact and placed in a glass container filled with a mixture of 70% (ethanol 99%) alcohol and 30% water. Roots were analysed at the AgResearch facility in Ruakura, Hamilton, using a

STD 4800 Epson Perfection V800™ photo scanner. The roots were prepared by washing them off with clean water and removing all foreign matter. They were then cut at the base to separate them and flailed onto a glass plate. After scanning the flailed roots, the researcher used the WIN-RHIZO Pro™ software program to analyse the roots for the criteria reflected in Table 20. The data was exported into an Excel™ spreadsheet and summarised for average, minimum and maximum values.

Yield assessments

Yield assessments commenced on 30 January 2019. Within each treatment, five plots of 3 m in onion bed length and width were selected for yield assessment. Treatment one was further split into A and B to determine if there were differences in results correlated to the elevation anomalies in the paddock (Figure 34). The plots were positioned so as not to be under a spray track and to represent each of the five towers of the centre pivot irrigator. The three-meter areas were marked out with white trial pegs. All onions within this area were hand-pulled, and the leaves were hand clipped. The number of bulbs was recorded, the number of rots[16] and pipers[17] was counted. Each onion's diameter was measured using a Bluetooth™ enabled digital Willowbanks electronic calliper (Willobanks Electronics Limited, 2019). The data was uploaded in-field to a mobile phone and then downloaded directly into an Excel™ spreadsheet. All onions were then bagged up and weighed on a mobile in-field scale.

Collected data was processed in an Excel™ spreadsheet where the gross yield, marketable yield per hectare and the percentage pipers were calculated for each treatment. The bags were removed from the field and stored for further processing.

[16] Rots imply onions bulbs that have broken down through bacterial infection
[17] Pipers are defined as onions that have initiated flowering.

Size profiling

The data retrieved from the yield analysis were used to calculate the sizing profiles against the packhouse standards. Onion bulbs were measured in-field with a digital calliper. The data was uploaded in-field to a mobile phone and then downloaded directly into an Excel™ spreadsheet.

Post-harvest Quality Control assessment

The post-harvest quality assessment was done by the Quality Control (QC) team at the onion packhouse of ASW in Pukekohe from 05 April 2019 to 15 April 2019. One bag (20 kg) of onions was retained from the yield assessments and sent to the packhouse for QC analysis. The QC team took all the onions out of the bag and laid them out on a table. The bulbs were counted. A team of two people did the assessments; one person evaluated the bulb while the other person recorded the data. Each bulb was evaluated against the following set of criteria for visual and physical properties:

- Rots: Visual and physical assessment for presence.
- Skin splits: Visual assessment for presence.
- Skin tensile strength: Physical feel of bulb.
- Skin retention: Physical rubbing of bulb.
- Skin colour: Visual assessment for quality and uniformity of colour.
- Thrips: Visual assessment for presence.
- Sunburn: Visual assessment for presence.
- Harvest damage: Visual assessment for presence.
- Pipers: Visual assessment for incidence of flowering.

Other: Any other visual abnormality that might influence bulb quality.

Post-harvest fruit firmness

One 20 kg bag of onions was retained from the yield sampling for each treatment. These bags were put into storage for 78 days at ambient temperature. From these bags, 20 onion bulbs were selected randomly for firmness testing at the Eurofins Bay of Plenty Ltd laboratory in Kerikeri on the

2de of May 2019. The onion bulbs were analysed with a WEL™ electronic penetrometer, fitted with an 11 mm probe. It measured the amount of force needed to penetrate the onion bulb 8 mm in depth at a speed of 8mm/s in kilogram force. The WEL QALink™ application allowed configuration of the penetrometer, displayed the measured forces and relayed the peak firmness figure (as determined by the yield point) into an Excel™ spreadsheet in real-time. Additionally, it provided a real-time graph of the firmness test results. The means for each treatment was calculated and graphed.

Financial data

Financial data was recorded for all fertiliser inputs by keeping a record of the product, price and volume used. The cost of the compost was recorded, and the yield data from the yield assessments was used to calculate financial results.

Statistical analysis

The researcher acknowledges the limitation of some of the datasets. In-field sampling was done at variable intensities for different data sets. This was due to the volume of the work as well as the commercial nature of the trial. For example, the yield results were derived from sampling five plots of three meters from five different treatments. From each plot, an average of 300 onions were sampled, giving a total of 7500 onions.

For plant roots, only five plants from each treatment (25) were analysed. This influenced the statistical significance of those variables. Data for firmness, roots and yield were subjected to analysis of:

1. Test of Homogeneity of Variances
3. Analysis of Variances (ANOVA)
5. Post Hoc Tests

Data were analysed with the IBM SPSS™ statistical program (Field, 2005) and significance were valued at $P<0.05$.

Fertiliser inputs

Fertiliser inputs were measured on a weekly basis by keeping a record of the products and volumes used for the duration of the trial. All records are available on request.

4.3.1.4 Results and Discussions

Soil chemical analysis

Figure 29 shows the results for each treatment from the chemical analysis that was conducted before applying the base fertilizer, at time of planting and after harvest. Analysis of pH, extractable Olsen P (P), Potassium (K), Calcium (Ca), Magnesium (Mg) and the Cation Exchange Capacity (CEC) Sodium (Na), total carbon and organic matter of the soil were compared.

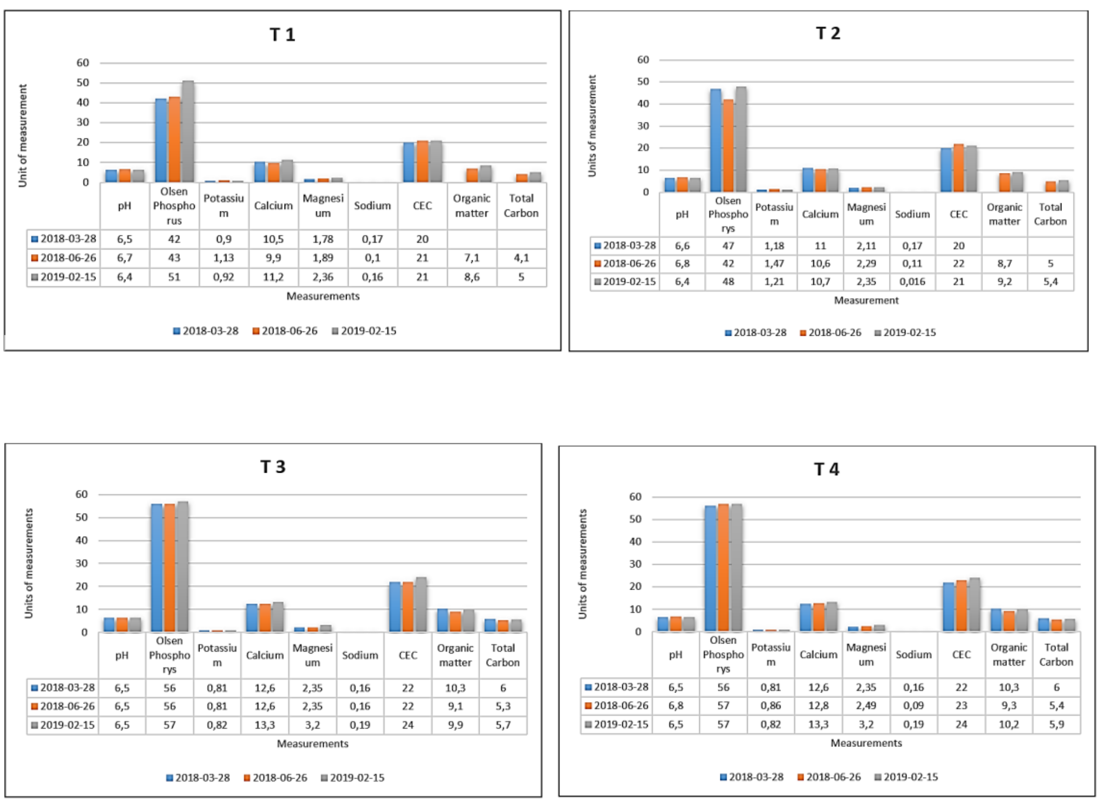


Figure 29: Results of the soil chemical analysis for Treatments 1-4. (See Appendixes G, H, I, and J).

In T 1 and T 2, the P valued increased from planting to harvest. These treatments received liquid phosphate in the form of Agri-APP (N 15.4%, P 22.6%) @ 60 l/ha after planting as part of the fertigation regime. The pH, K, Ca, Mg and CEC remained constant for all three measurements. This indicates that the crop did not remove more nutrients than what was applied, and that no build-up of nutrients took place.

The organic matter content and the total carbon in all treatments increased over the time period. This indicates that it could not be attributed to the application of compost alone as only T 2 and T3 received compost.

Soil texture analysis

In Figure 30 the amount in percentile of sand, silt and clay at 150 mm, 300 mm and 450 mm soil depth are shown.

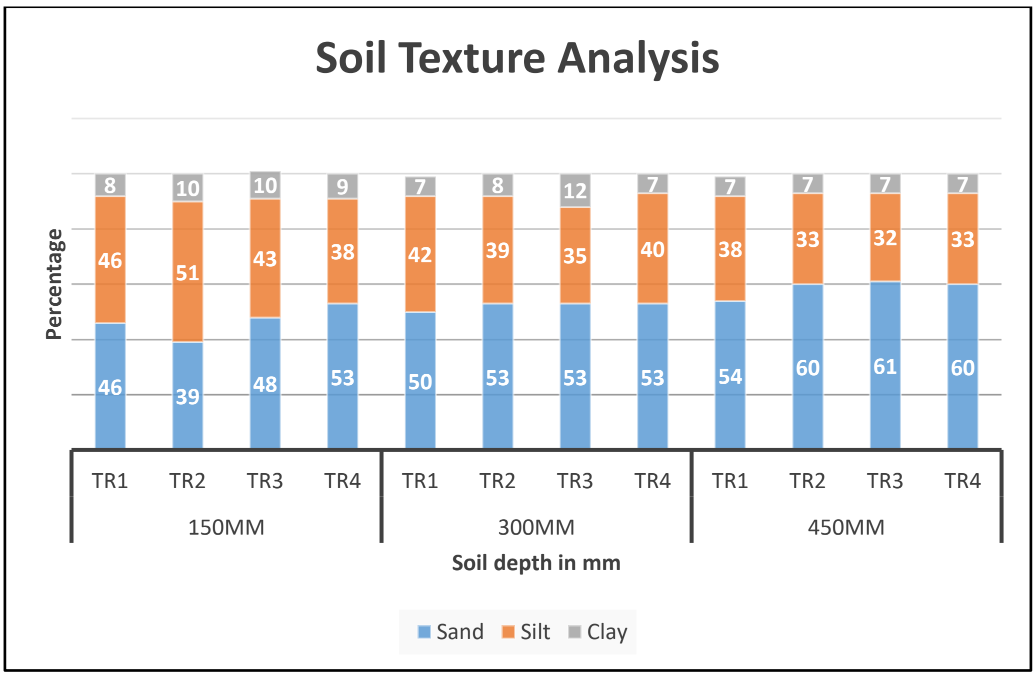


Figure 30: Soil texture analysis for treatment 1,2,3 and 4 at 150mm, 300mm and 450mm soil depth. Percentage sand, silt and clay are reflected for each treatment at depth.

Analysis of soil texture indicated relatively homogeneous soil profiles across the four treatments. However, at 150 mm depth, there was a variance in the sand and silt ratio. The clay contents of the soil fluctuated between seven and twelve percent with T 3 at 300 mm depth the highest. Treatment 3 also had the highest percentage of sand at 450 mm depth with 61 percent.

Soil microbial analysis

Samples were taken before planting and after harvest to determine the effect of the cropping cycle on soil microbial parameters. The data was conditionally formatted using colour scales to indicate best-case scenario in green and worst-case scenario in red. The data is an indication of practically significant differences and were not statistically analysed.

Table 16: SFI results from pre-plant analysis indicating critical microbial parameters regarding Fungi, Bacteria, Flagellates, Amoebae and Ciliates.

SFI report	2018-07-04											
Invoice number	5857											
Pre plant		>30	>300	>40	>400	0.75-1	>0.10	>0.10	0.75-1	>10000	>10000	<47
		Active Fungi	**Total Fungi**	**Active Bacteria**	**Total Bacteria**	**TF:TB**	**AF:TF**	**AB:TB**	**AF:AB**	**Flagellates**	**Amoebae**	**Ciliates**
T 1	Fertigation	5,64	117,01	24,53	490,88	0,24	0,05	0,05	0,23	21555,53	2155,09	715,25
T 2	Fertigation + Compost	10,02	167,29	16,52	317,9	0,53	0,06	0,05	0,61	22019,74	7316,09	439,98
T3	Standard + Compost	1,18	250,93	36,3	398,93	0,63	0	0,09	0,03	7255,78	4368,28	724,63
T 4	Standard	1,18	158,48	18,42	361,53	0,44	0,01	0,05	0,06	9078,32	9078,32	1312,68

Table 16 shows the results for the microbial analysis pre-plant. Treatment 2 had the highest number of Active Fungi (AF), while T 3 had the highest number of Total Fungi (TF) and Active Bacteria (AB). Low fungal biomass and fungal activity were observed for all treatments. The overall percentage of active fungal activity was critically low. The high flagellates and low amoebae indicated lack of diversity and inconsistent nutrient cycling. The soil was bacterially dominated, as indicated by the TF to Total Bacteria (TB) ratios.

Table 17: SFI results from post-harvest analysis indicating critical microbial parameters regarding Fungi, Bacteria, Flagellates, Amoebae and Ciliates.

SFI Report	2019-02-22											
Invoice number	5697											
Post harvest		>30	>300	>40	>400	0.75-1	>0.10	>0.10	0.75-1	>10000	>10000	<47
		Active Fungi	**Total Fungi**	**Active Bacteria**	**Total Bacteria**	**TF:TB**	**AF:TF**	**AB:TB**	**AF:AB**	**Flagellates**	**Amoebae**	**Ciliates**
T 1	Fertigation	3,66	183,65	20,53	429,85	0,43	0,02	0,05	0,18	6200,66	6200,66	37,69
T 2	Fertigation + Compost	3,27	152,74	21,77	512,22	0,3	0,02	0,04	0,15	6148,04	19988,34	663,25
T 3	Standard + Compost	0,54	267,88	7,42	517,91	0,52	0	0,01	0,07	2020,48	4042,42	67,06
T 4	Standard	0,65	224,83	4,42	406,93	0,55	0	0,01	0,15	8294,08	6146,33	399,28

When Table 17 (Post-harvest) is compared to Table 16 (Pre-plant), it becomes apparent that the addition of compost to T 2 and T 3 returned a null hypothesis for fungal stimulation. The addition of compost increased the TB in both those treatments from which it could be derived that the compost lacked fungal activity and was bacterially dominated.

Compost

The compost was produced by Daltons® from Matamata (Figure 31). Twenty cubic meters of compost with a bulk density of 75% was applied per hectare to T 2 and T 3. It was analysed for chemical composition by Hill before application.

The pH was high at 7.8, and the electrical conductivity measured at 2.7 MS/cm. The organic matter content of 67.7% exceeded the greater than 25% requirement. The recipe aimed to achieve a C/N ratio of 1: 25 (E. Ingham, 2005). The analysis showed a 1:28 result. The compost had a temperature of 48°C, which indicated a slightly immature product.

Figure 31: Compost delivered to the trial plot.

As discussed under soil microbial analysis, the compost did not enhance the fungal activity of the soil profile as was expected.

Drone mapping

In Figure 32, varietal differences were clearly visible. Varieties which matured early (tops down)[18] showed up as yellow areas on the map. Also showing up as dark spots were the low-lying areas where no growth took place. It was valuable to ground truth the visual differences and to overlay these images with other data sets. This technology will be used more extensively in the coming season to prepare fields for planting and to rectify drainage where needed. There were no visible differences between the treatments observed from this map.

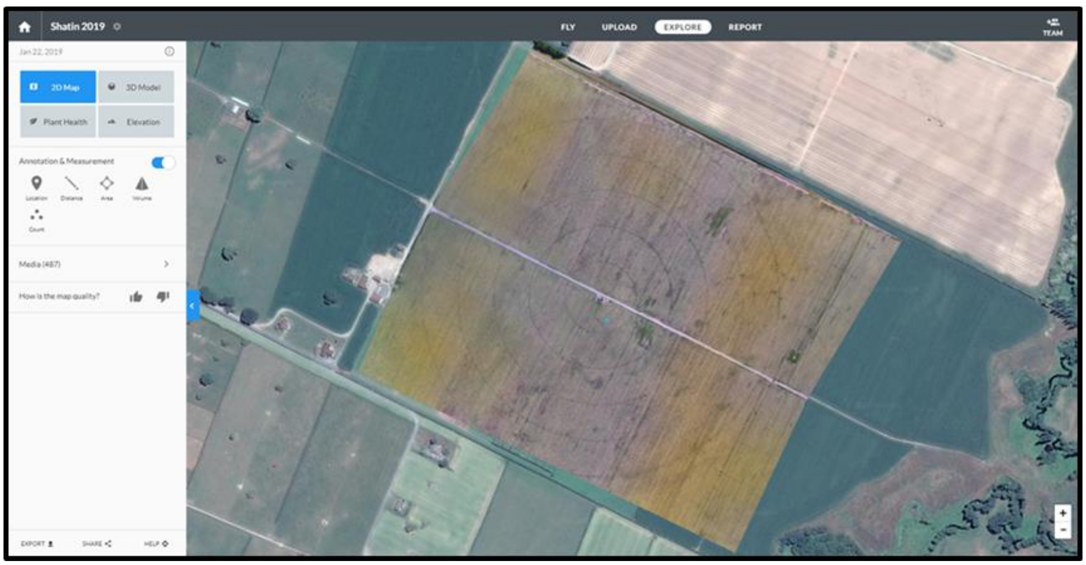


Figure 32: A two-dimensional map of the trial area (Source: DroneDeploy, 2019)

The software that compiled the map in Figure 33 interpreted brown areas as “unhealthy” and green areas as “healthy”. This was misleading unless clarified; early maturing varieties would show up as unhealthy as a result of their leaves toppling over and were thus showing up on the map as brown. It has to be stated that the normalized difference vegetation index (NDVI), which is a graphical indicator used to analyse remote sensing measurements and assess whether the terrain observed contains live green vegetation or not, were not

[18] When onions reach maturity, the neck of the bulb closes, and this causes the leaves to topple over.

used for this map set. This was due to the fact that the researcher's drone did not have the NDVI functionality.

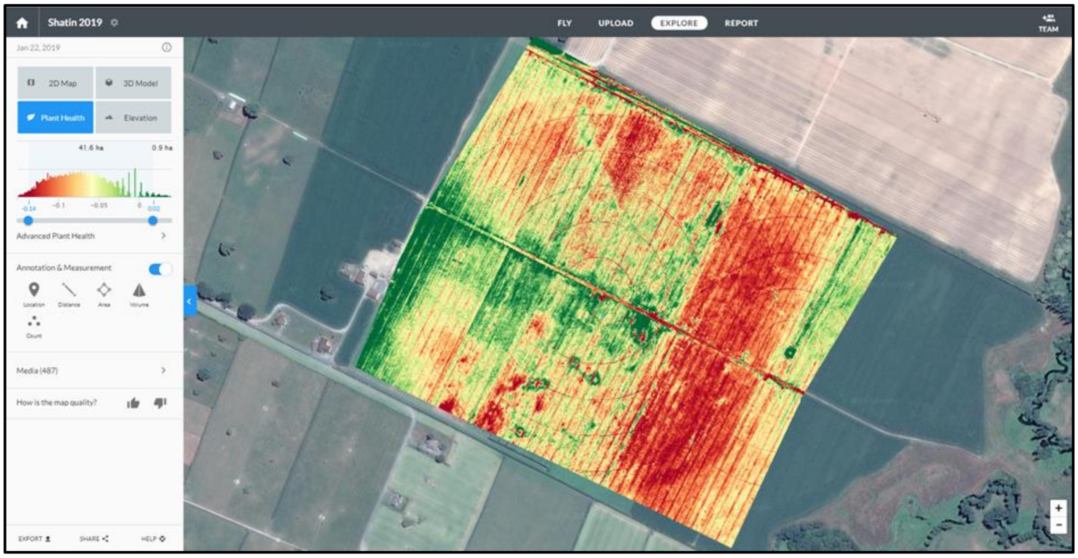


Figure 33: A plant health map from the trial area (Source: DroneDeploy, 2019)

Bare ground will show as red on the map. Again, there is no clear differences between Treatments on the map. What is important to notice is the variances within same varieties.

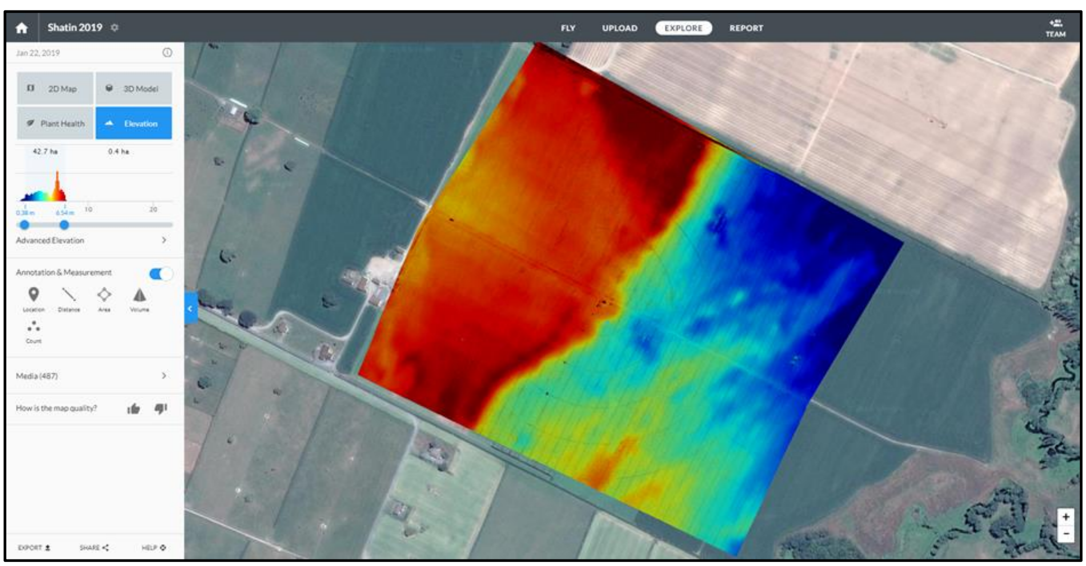


Figure 34: An elevation map from the trial area (Source: DroneDeploy, 2019)

Ground truthing these anomalies indicated a relation to ponding, high laying areas and soil differences. It is also evident when looking at Figure 33 in conjunction with Figure 34 that elevation played a part in maturity and or plant health. Also, the importance of drainage shows up again. On this map, higher elevations are indicated as red areas and low-lying areas are in blue Figure 34. Comparing the three maps as a unit highlighted the correlation between varieties, drainage and elevation to the researcher. For instance: the dark red triangle on the top right of the elevation map Figure 34 had an influence on the maturity of the onions as seen for the same triangle in Figure 33. For this reason, T 1 was split into 1A (Higher elevation) and 1B (lower elevation) so see whether there are any significant differences observed within the trial.

Weather data

The weather data was constant for all treatments. A total of 130 mm of irrigation were applied while the trial received 504.7 mm rainfall in the corresponding period (Table 18). Full weather data is shown in Appendix O (Evapo-transpiration), Appendix P (Rainfall), Appendix Q (Degree days), and Appendix R (Temperature).

Table 18: Weather data representing the Onion Fertigation Trial locality and duration in Matamata.

Report length 185 days	**Total**	**Daily average**
ETo	854.33 mm	4.62 mm/day
Irrigation	130.00 mm	
Rain	504.7 mm	
Solar energy	74373.2 Ly	402.20 Ly/day

Rainfall and irrigation

In Figure 35, it is shown that there were seven incidences of irrigation with five of them being inclusive of fertigation. The 504.7 mm of rainfall were measured over 21 rain events.

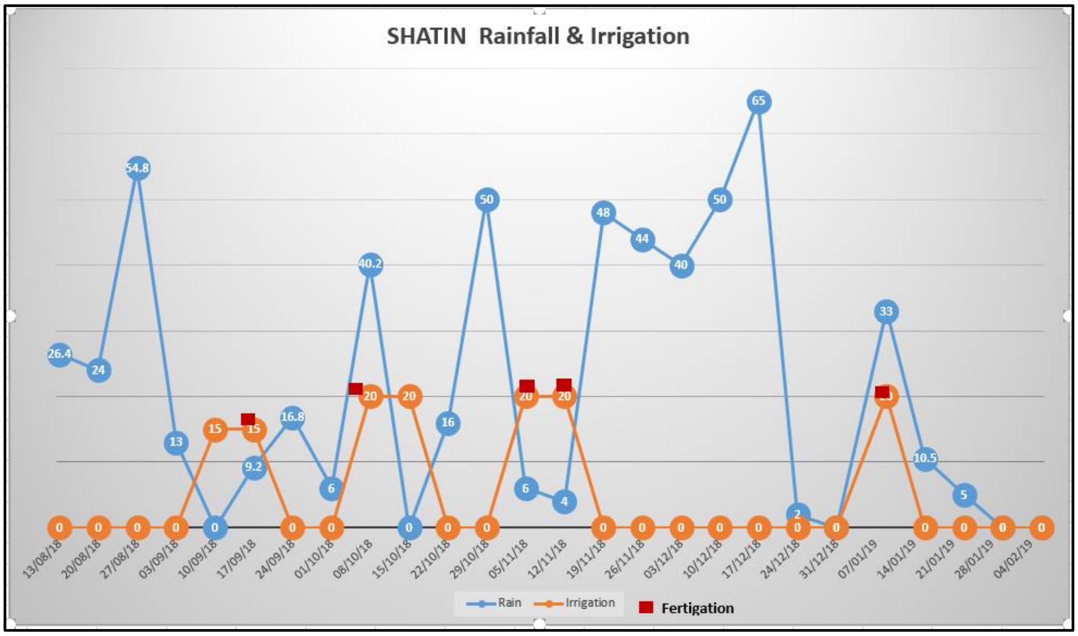


Figure 35: Weekly incidences of rainfall (blue) and irrigation (orange) in mm per week are overlaid by the fertigation dates (red squares) for the Onion Fertigation Trial area in the time period.

The 21 rain events impacted on the windows of opportunities available for fertigation. The researcher will reflect on the consequences of this observation in Chapter 5. The data is constant for all treatments and did not have an impact on the individual treatment's performances.

Soil moisture analysis

Soil moisture was monitored with neutron probes in each treatment. The full results of these findings are reflected in Appendices K, L, M and N. There was no soil moisture difference in the top 150 mm of the soil profile between the treatments due to irrigation management and rainfall. There were some differences in the deeper layers, but these were not tested for significance as the differences could be attributed to soil texture variations.

Dry leaf analysis

Although the researcher did not analyse the dry leaf data statistically, the observations are based on practically significant differences and Table 19 is based on descriptive statistics. Treatments that received compost, returned a higher analysis of N than no-compost Treatments. The combination of fertigation and compost (T 2) resulted in the highest analysis for Nitrogen (N), Potassium (K), Calcium (Ca), Magnesium (Mg), Manganese (Mn), Zinc (Zn), and Boron (B). Treatment 4, which received the standard fertiliser programme had lower Mn, Iron (Fe) and Zn results. The difference in the level of Iron between T1 and T 4 could not be contributed to the application of compost because it received none.

Table 19: Results from the dry leaf analysis of T 1,2,3, and 4 in the Onion Fertigation Trial.

Chemical analysed	**T 1**	**T 2**	**T 3**	**T 4**
Treatment received	F[19]	F + C[20]	S + C[21]	S[22]
Nitrogen* %	1.9	2.2	2.1	1.7
Phosphorus %	0.31	0.26	0.29	0.26
Potassium %	1.7	2.1	1.8	1.8
Sulphur %	0.46	0.52	0.53	0.49
Calcium %	0.49	0.58	0.52	0.48
Magnesium %	0.12	0.13	0.13	0.12
Sodium %	0.013	0.02	0.015	0.012
Iron mg/kg	40	35	33	29
Manganese mg/kg	47	52	43	26
Zinc mg/kg	20	21	19	14
Copper mg/kg	4	4	4	4
Boron mg/kg	21	21	19	18

Root analysis

Root data was subjected to a Test of Homogeneity of Variances and the result based on means (Levene) showed no significant difference. The one-way ANOVA found that there was a significant difference (P.0.05) between groups on average root diameter. The Post Hoc Test (Bonferroni) indicated significant differences between T 2 and T 3 ($P<0.05$) and a slight difference ($P<0.1$) between T 3 and T 4 on average root diameter. Onions require surplus amounts

[19] F = Fertigation
[20] F + C = Fertigation and compost
[21] S + C = Standard and compost
[22] S = Standard

of fertilisers to produce a viable crop. Because of “meagre and insufficient” root systems, onions are weak nutrient scavengers (De Melo, 2003). The researcher postulated that fertigation should have a positive effect on root growth by servicing the roots more uniformly with nutrient availability.

Table 20: Root analysis summary showing the means value of root length cm, root projected area cm², root surface area cm², average root diameter mm, root length per volume cm/m³, root volume cm³, dry root weight g, followed by the minimum and maximum values of each.

Measurement		T 1	T 2	T 3	T 4
Length (mm)	Average	804.42	808.59	737.39	938.89
	Max	1025.90	959.54	1007.01	1519.50
	Min	532.44	601.55	599.10	593.39
Project Area (cm²)	Average	62.12	57.55	62.17	69.51
	Max	75.55	73.48	88.00	114.40
	Min	44.30	43.79	51.77	48.23
Surf Area (cm²)	Average	195.17	180.80	195.32	218.37
	Max	237.36	230.86	276.46	359.39
	Min	139.16	137.57	162.65	151.51
Avg. Diameter (mm)	Average	0.78	0.71	0.84	0.74
	Max	0.85	0.77	0.88	0.81
	Min	0.72	0.64	0.72	0.67
Length per Vol (cm/m³)	Average	804.42	808.59	737.39	938.89
	Max	1025.90	959.54	1007.01	1519.50
	Min	532.44	601.55	599.10	593.39
Root Volume (cm³)	Average	3.79	3.23	4.14	4.05
	Max	4.37	4.42	6.04	6.76
	Min	2.89	2.42	3.04	2.98
Dry Root Weight (g)	Average	2.20	2.06	2.76	2.84
	Max	3.10	3.30	4.00	4.50
	Min	1.80	1.30	1.80	1.90

Plant roots were analysed to identify differences between the treatments and to test this theory (Table 20). The results in Table 20 returned a null hypothesis based on observation. The standard (T 4) returned green (conditional formatting for best case scenario) on five of the seven measurements. From the root analysis, it was surprising to learn that T 4 produced the highest level of root length, root area, surface area, and length per volume. Especially since T 4 did not receive liquid phosphate in the form of fertigation but received a standard phosphate program. The potential increase in root performance did not materialise in higher yields as was expected.

Yield

Yield results reflected in Figure 36 were calculated from the five plot assessments that was done for each treatment. The in-field data was reduced to 90% of the weights measured to reflect true yield potential. This factor is a constant used in ASW for field assessments.

Treatment 1 (Fertigation), was divided into T 1A and T 1B after evaluating the elevation drone map (Figure 34) to capture the observed differences. With all other factors constant, it clearly shows the influence drainage and soil moisture content have on yield with a ten-ton difference in marketable yield between the high and the low laying area.

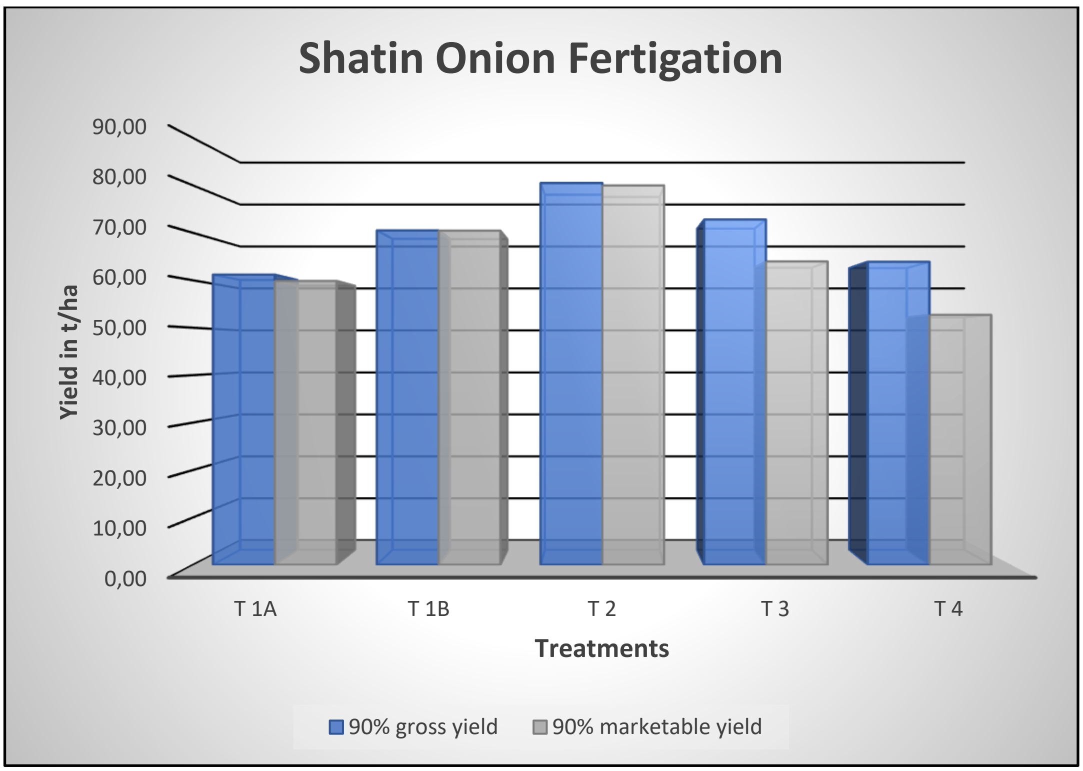


Figure 36: Yield results for the Onion Fertigation trial indicated a 10 t/ha increase with compost application and a further 10 t/ha increase with fertigation.

Statistical analysis of yield data was done for gross yield. The Test of Homogeneity of Variances (Levene) returned a significant difference based on means. The one-way ANOVA showed a significant difference between groups and the Post Hoc Test (Bonferroni) identified significant differences between T 1A and T 2, T 1A and T 3 as well as between T 2 and T 4 ($P<0.05$). There was a slight difference between T 1B and T2 ($P<0.1$).

Treatment 2 (Fertigation + compost) had the highest gross and marketable yield with 81 and 80 t/ha respectively. The influence of compost is highlighted when we compare T 2 and T 3. Both received fertigation, but T 2 yielded 16 t/ha more with the inclusion of compost. The difference between the best-case (T 2) and worst-case (T 4) was 27 t/ha. The difference in marketable and gross yield for T 4 and T 3 was due to flowering as seen in Table 21.

Size profile

The size profiling is an indication of quality. All sizes of onions are needed and are marketed but size does influence yield and there is a preferred band for the export market.

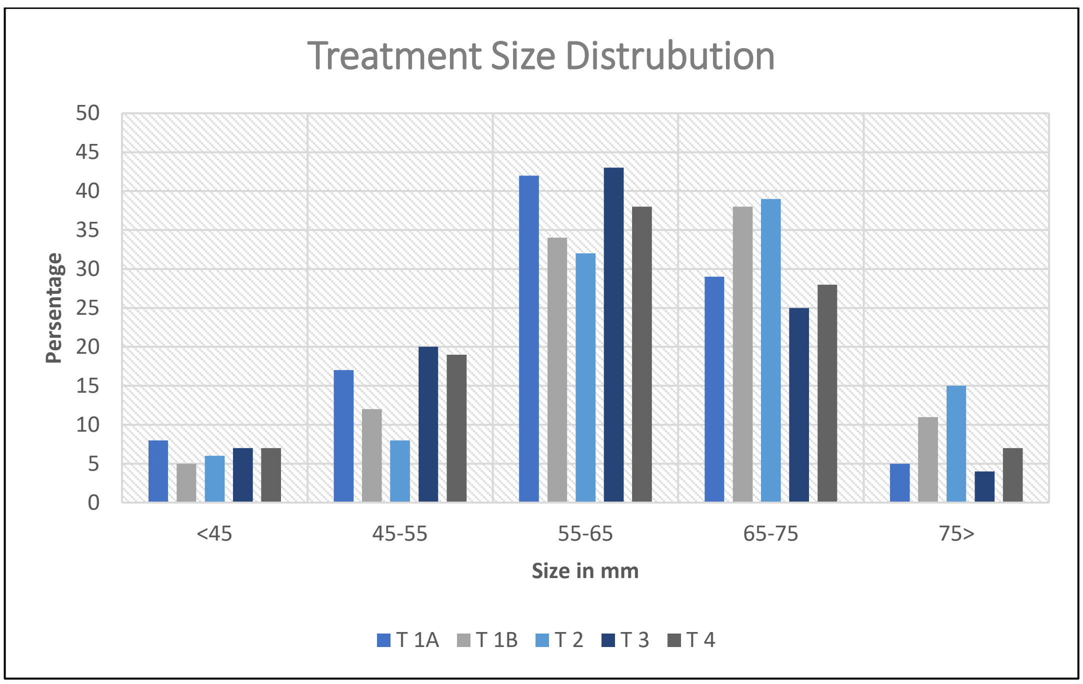


Figure 37: Size distribution for each Treatment in bands of <45 mm, 45-55 mm, 55-65 mm, 65-75 mm and >75 mm. the percentage of onion bulbs representing each size band is compared from the Onion Fertigation Trial.

When the sum of the first two size bands (Figure 37) were compared between the treatments then it is observed that T 1A had the smallest onions with 25%.

When the sum of the last two size bands were compared, T 2 had the biggest onions with 54%. It is observed that fertigation in conjunction with compost resulted in bigger onions. A Test of Homogeneity of variances (Levene) showed a slight significant difference (P<0.1) for average diameter between treatments based on means. The one-way ANOVA returned a significant difference between groups. The Post Hoc Test (Bonferroni) observed no significant differences between T 1A and T 3; T 1A and T 4; T 1B and T 2 as well as between T3 and T 4.

Quality control report

The quality control (QC) report (Table 21) was generated by evaluating a representative sample of onion bulbs out of each treatment at the packhouse. It was an indication of onion bulb quality, measured against a set of criteria. Skin splits, skin tensile strength, skin retention, skin colour, insect damage, sunburn and incidence of flowering (Pipers) were measured.

Table 21: Quality report conditionally formatted on a colour scale to indicate best-case scenario in green and worst-case scenario in red for each treatment against set criteria.

Treatment	Skin splits	Skin tensile strength	Skin retention	Skin colour	Thrips damage	Sunburn	Pipers
1A	76%	54%	65%	52%	8%	4%	1%
1B	85%	31%	72%	64%	3%	6%	0%
2	96%	92%	83%	40%	2%	28%	0%
3	85%	64%	76%	58%	7%	1%	24%
4	86%	84%	78%	75%	7%	1%	7%

A Test of Homogeneity of variances (Levene) showed a significant difference (P<0.05) for “Pipers” between treatments. From the QC report, it is derived that T 2 produced the best quality onions. Treatment 2 had 96% of the bulbs scored as excellent in Skin splits, 92% of bulbs scored as excellent on Skin tensile strength, and 83% scored as excellent on Skin retention. It had the least amount of Thrips damage and had 0% Pipers. Treatment 2 had the lowest number of bulbs scored as excellent on Skin colour. It also had the highest incidence of Sunburn.

Fruit firmness

Fruit firmness data were subjected to statistical analysis. The variability within treatments is greater than that between treatments, hence there is no significant difference (P>0.05) on the means for probe average for fruit firmness. The researcher would like to explore this variability. This shows that there is a large genetic variability within the variety. Fruit firmness is an indication of the shelf live and storage capability of onions.

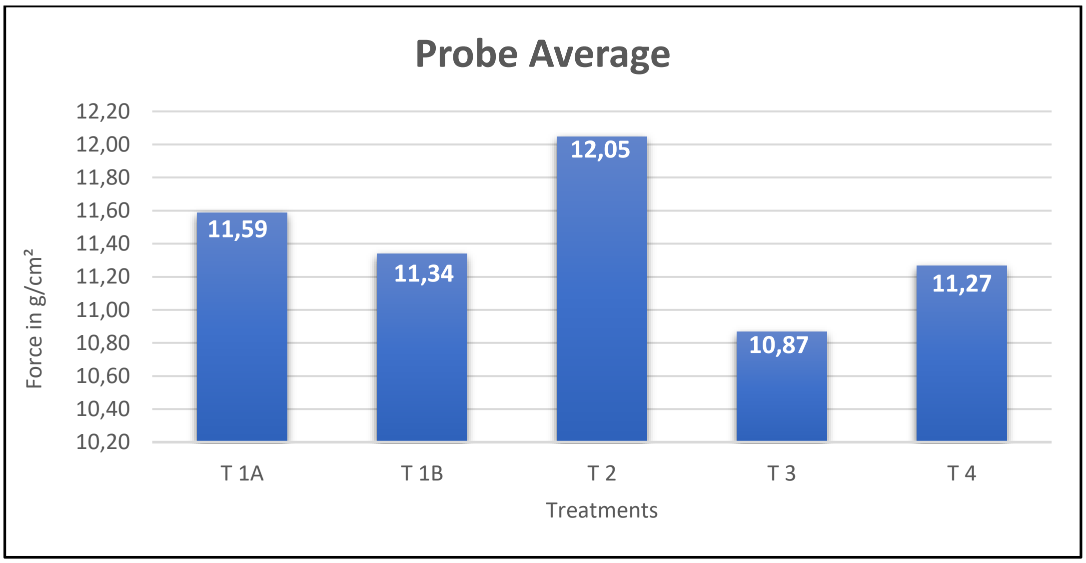


Figure 38: Pressure tests done for fruit firmness, compared between treatments in kgf from the Onion Fertigation Trial.

The probe data that measured fruit firmness (Figure 38) showed that T 2 had the firmest fruit with 12.05 kgf.[23] while T 3 had the softest onions with 10.87kgf. Treatment 3 had the softest fruit which correlates to the fact that it had the most incidences of Pipers (Table 19) which have a detrimental effect on fruit firmness.

[23] The measurement for the fruit firmness tests used by the researcher is expressed in kilogram force (kgf).

Financial data

The financial results of this trial have a direct impact on the financial sustainability of ASW. It was therefore important, to not only look at the yield and quality results, but to also consider the financial implications of the input and output of the trial.

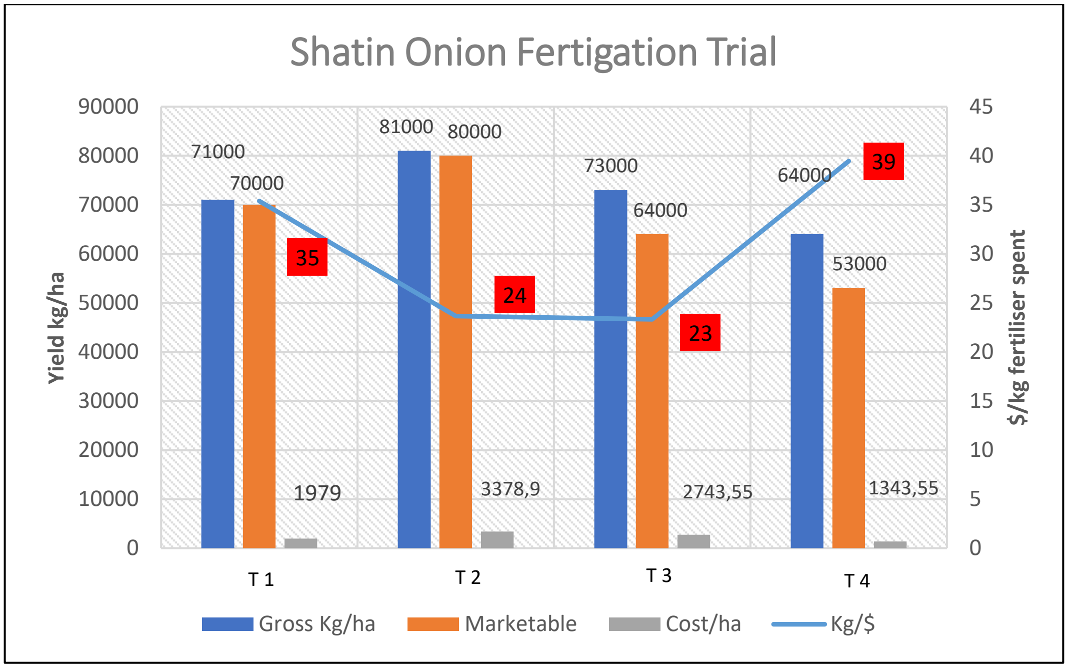


Figure 39: Comparing gross yield in kg/ha and marketable yield in kg/ha to the total fertiliser cost in $/ha for each treatment. The kg onions produced per $ fertiliser spend (kg/$) is then indicated in the red squares after dividing the marketable yield by the total fertiliser cost.

Figure 39 indicates that T 2 produced the highest marketable yield/ha with 80,000 kg/ha. The lowest yield was in T 4 with 53000 kg/ha. The treatment yields were compared to their respective fertiliser cost/ha. The compost cost pushed the fertiliser input cost to $3378,9/ha while the standard program only cost $1343.55/ha. The number in red is the amount of onions in kilograms that were produced for every dollar spent on fertilisers.

The potential effect on income/ha is very relevant to achieving Objective 2 of the research projects in that the success of the trial is to a great extent determined by the potential increase in income.

In Figure 40, the assumption is made that one ton of red onions could be worth $700. This dollar value is not a reflection of the real value of the onions sold from the trial but is a mere constant factor used for comparing the Treatments against each other.

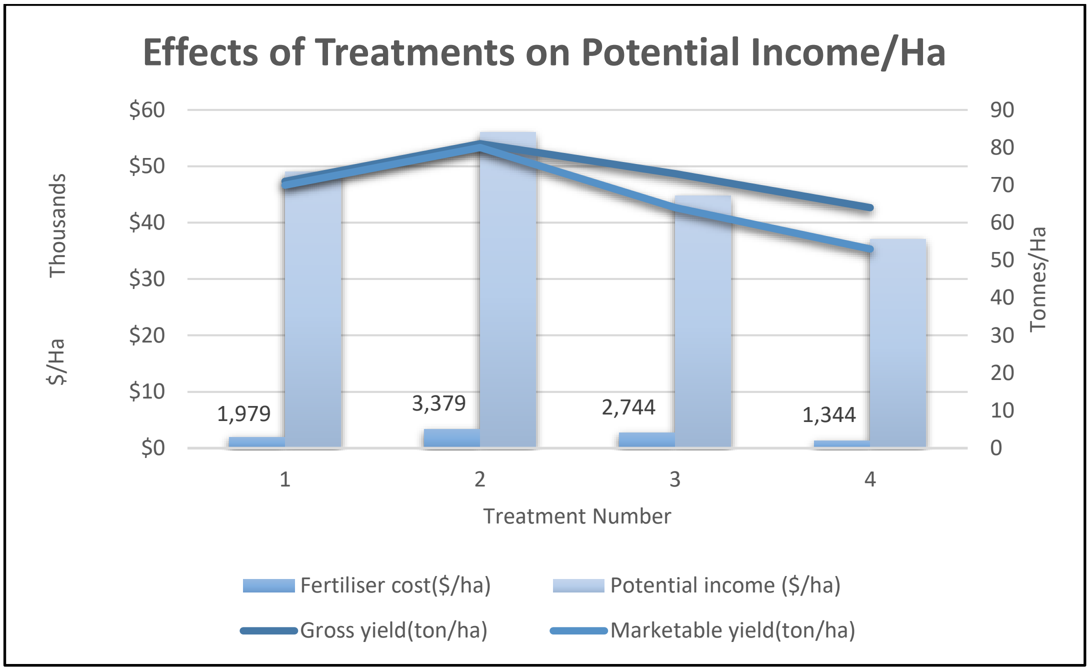


Figure 40: Effect of Treatments on Potential Income/ha for the Onion Fertigation Trial.

From this calculation then, it was derived that T 2 had a potential income of $56000/ha compared against the standard of T 4 with $37100/ha. The difference between the two ($18900/ha), extrapolated over the total area of 36ha, could potentially have had a positive effect on income of $680,000.

Fertiliser inputs

Table 22: Fertiliser inputs as total elemental values of N, P, K, Ca, Mg and S per hectare for each treatment.

Number	N	P	K	Ca	Mg	S	Treatment
T 1	167	115	285	83	74	166	Fertigation
T 2	167	115	285	83	74	166	Fertigation + Compost
T 3	141	118	262	154	70	187	Standard + Compost
T 4	141	118	262	154	70	187	Standard

Potassium were 23 kg/ha and Mg only 4kg/ha higher in T 1 and T 2 compared to T 3 and T 4 (Table 22) because those elements were also fertigated. Sulphur were higher in T 3 and T 4 as a result of the base and side dressing programme associated with the standard. The strategy with P applications was to half the P application before planting and to supplement the difference with two liquid applications after planting in the fertigated areas to see if this had an influence on the yield and or root development.

The objective to reduce added N through the fertigation did not materialise. This was because the plants lacked vigour and with the wet season on hand, it was felt at the time, that the best practice was to supplement the crop with an additional N application as a side dressing. This pushed the total N, on the fertigation part of the trial, to above that of the standard. This was necessary to manage the potential loss of income from a commercial planting of onions. This is important as it demonstrates the impact of commercial realities on experimental design.

4.4 Triangulation

The researcher used triangulation as shown in Figure 24 to compare, integrate and interpret the results from the qualitative and the quantitative research.

The qualitative research identified the fact that NZ has a clean green image (Table 12) and that the customers of ASW expected the company to be sustainable (KB, Interview, 19 March 2019). Sustainability is embedded in the Māori values (Table 2) and is advocated by (Hatt et al., 2016; Ingram, 2007; Moller et al., 2008; Renting & Van Der Ploeg, 2001).

The potential for ASW to explore this perception of “Clean Green”, and to tap into the NZ and Matamata Tourism opportunities were mentioned (Table 14). This corresponds to the findings of the literature review (Section 2.2.2) and supports the view of interviewees (AT, interview, 08 April 2019).

The advantage of maintaining operational flexibility and continuing to differentiate from the competition with niche products was highlighted (Appendix C and Section 4.2.2.1). This notion of flexibility was confirmed with the quantitative research where high rainfall caused the researcher to revert to spreading granular fertilisers (Section 4.3.1.4. - Fertiliser Inputs).

Land, and the land ownership model, are a contentious issue. Figure 17 identified land as an integral part of sustainability. Griffin (2019) introduced the concept of loss of productive agricultural land to urban encroachment due to population growth and property value in Section 2.1. This is further supported by the history of ASW mentioned on page 19 and the cost of land shown in Table 1. Land is part of the company’s core values (Figure 7) and is also central to Maori values (Table 2). The access to land was discussed in Section 3.6 as part of the needs statement for the Onion Fertigation Trial. The current ASW land ownership model was identified as a weakness (Table 13). Future pressures on land ownership regarding nitrogen discharge and the need for a Farm Environmental Plan were mentioned by the Waikato Regional Council (AT, Interview, 08 April 2019).

The interconnections of land with water (Waikato river) and the need for stewardship of land for the benefit of future generations is mentioned in Table 2 as part of Māori values. Good housekeeping, and to keep properties neat and tidy, influenced people's perceptions of stewardship. Land was mentioned as a threat by five interviewees (Table 15).

Soil health reflected strongly in both qualitative and quantitative research. The topic of soil health is discussed at length in Section 2.4.1 and was mentioned by seven interviewees as a threat. It also appeared numerous times in Section 4.2.3 under general comments. All three pillars of soil health mentioned in Figure 18, influenced the outcomes of the quantitative research. The Chemical (Figure 29), Physical (Figure 30) and Biological (Table 16 and 17) composition of the soil mentioned in Table 3 had an adverse effect on the yield and quality of the onion crop.

The value of geospatial data and the effect of elevation/drainage on yield was emphasized with the drone mapping (Figure 34). The ability to manage data was identified as a weakness (Table 13), and the options available for Geographical Information Systems (GIS) to address this weakness were mentioned. This coincided with the concept of Precision Farming and the utilisation of variable rate fertiliser spreaders in conjunction with a GIS platform to address some of the variables identified in the soil analysis (AH, Interview, 14 March 2019).

The application of compost contributed to the yield increase achieved (Figure 36). Soil microbial analysis indicated low fungal biomass and a bacterial dominated compost (Table 16 and 17). The need to utilise compost with high attributes of microbial life was demonstrated. The combination of fertigation and compost resulted in an increased onion yield of 27 t\ha (Figure 36). The combination of fertigation and compost resulted in the largest size profile of 54% > 65mm (Figure 37). Compared to the quality control criteria, the combination of fertigation and compost resulted in the highest quality onions (Table 21). Fertigation and compost also resulted in the firmest fruit (Figure 38). From the dry leave analysis (Table19), it is shown that the combination of fertigation and compost resulted in the highest uptake of nutrients. The combination of fertigation and compost was the most expensive input option for fertiliser regimes (Table 22).

The research objectives had to contribute to a positive effect on the People (Societal), Planet (Environmental) and Profit (Financial) aspects of sustainability (Palmer & Flanagan, 2016). The importance of financial sustainability was reflected in both the qualitative and quantitative research. Results from the on-farm trial indicated that although the combination of fertigation and compost was the most expensive input option for fertiliser regimes (Figure 40), it returned the highest yield and quality. Given these results and extrapolating the potential income to the 36ha treatment area, Figure 40 demonstrated the potential increased income.

Financial sustainability was identified as a weakness by the interviewees (Table 13), and seven people listed it as a threat (Table 15). The topic also featured prominently in Section 4.2.3. The Māori value of Arohatanga clearly states that stewardship agriculture can only be sustainable if farmers use practices that are socially acceptable and profitable (Section 2.4). The literature review indicated that fertigation techniques had the potential to reduce fertiliser usage whilst maintaining profitable yielding crops (Deavoll, 2019). The quantitative research pointed out that fertigation as an eco-agricultural principle was financially viable and advantageous (Figure 40).

Chapter 5: Summary

5.1 Introduction

This chapter presents an overview of the key findings and recommendations drawn from the data analysis of a Transdisciplinary Implementation of Sustainable Agricultural Principles in the Waikato Region of New Zealand.

The chapter begins with a discussion and a summary of key findings in Section 5.2. The researcher's reflection on the study and recommendations derived from the research is presented in Section 5.3. The chapter concludes with a discussion of opportunities for future research.

5.2 Discussion and Summary of Key Findings

The main objectives of this research project were:

1. To determine through qualitative research in the form of an interview process with various stake holders, their perception of sustainability and relevant themes for strategic change towards a thriving commercial vegetable farming business.

2. By way of quantitative research, to investigate the potential for successful implementation of sustainable agricultural production practices in support of soil health and plant health improvements by evaluating if:
    a. Fertigation techniques and
    b. Compost applications are advantageous in comparison to a standard fertilizer programme in terms of yield, quality and financial results.

The objectives of this study aimed to discover through transdisciplinary research, how socially acceptable and sustainable production practices could be successfully implemented in a commercial vegetable farming operation in the Waikato region of New Zealand, ensuring the commercial viability required for a thriving business.

The key findings related to Objective 1 are:

- Sustainability is no longer an option. It is a requirement for being a thriving business enterprise.

- Sustainability encompasses societal, environmental, financial and cultural aspects. All four these aspects are equally important.

The key findings relating to Objective 2 are:

- Given the yield and quality results of the on-farm trial and extrapolating the potential income benefit to the 36ha treatment area, it is a key finding of this research that an increased profit is possible utilising a combination of fertigation techniques and compost applications for onion production.

- Soil health is an integral part of sustainability, and all three components thereof influenced the outcomes of the research.

5.3 Conclusion

The regulatory environment (Waikato Regional Council), political role players (Ministry for Primary Industry), industry partners, landowners, co-workers and the customers of ASW expect the business to continually improve their sustainability position "*Our customers expect sustainability to be part of any businesses approach anyway*" (KB, interview, 19 March 2019). The question, therefore, is no longer whether ASW should become more sustainable, but it has become a question of how to implement the necessary change to be a sustainable and thriving business. This study clearly identified the strengths, weaknesses, opportunities and threats to ASW for becoming sustainable but also for not becoming sustainable.

It was clear from the research that an alternative to conventional farming would be needed if ASW wanted to become more sustainable. Soil health has been identified as a low hanging fruit for implementation of some of the eco-agricultural practices associated with agricultural sustainability.

The principles of soil health in regard to the chemical, biological and structural composition of soil have been tested in the on-farm trial with Onion Fertigation and the addition of compost. The results of this trial and the results of the qualitative research clearly indicated that it was possible to implement sustainable agricultural principles in the Waikato Region of New Zealand following transdisciplinary frameworks.

5.4 Reflection

The researcher was sensitized for the relationship between soil health, plant health and human health when his father was diagnosed with prostate cancer. His interest in vegetable farming and the ability of his children to continue the family legacy influenced the research proposal.

The researcher had a cognitive bias towards irrigation through his historical background with irrigation, and his first thoughts were to investigate the possibility to improve some of these factors through alternative irrigation methods. This research project could have stopped with the perceived success of the drip tape trial had it not been for the fact that the economic model proved unsustainable for ASW at that time.

The researcher realised that there had to be more to sustainability than just an improvement in yield. After forming the collaborative relationship between the academic institution and the industry partner, he embarked on a journey through academic study, on-farm trials and an interview process with relevant stakeholders to discover the hidden truth.

The realization that sustainability encompasses People (Societal), Planet (Environmental), Profit (Financial) and Cultural aspects, and that soil health involved the chemical, physical and the microbial aspects of soil, confirmed the complexity of the “wicked” problem. The researcher came to the conclusion that a transdisciplinary approach should be followed if change were to be implemented successfully in the business.

The literature review confirmed this discovery and enabled him to set the boundaries for the research project. Determining the research design through the philosophical models of SSM and Integral Theory greatly enhanced his capability to first, investigate the need for, and second to implement sustainable principles in a commercial vegetable production system.

The qualitative research identified focus areas for the business and led to quantitative research by way of the Onion Fertigation Trial. The commercial nature of the operation and the financial risks associated with doing large scale trials limited the validity of the data but also enabled the researcher to prove the fact that these principles were indeed implementable in such a way that it would contribute to the business being a thriving enterprise.

The collaborative nature of the study exposed the researcher to an incredible array of contributions through his contact with various stakeholders. Co-workers, politicians, people operating in the regulatory environment, landowners, academics, research institutions and industry partners all contributed to the outcome of this study.

Lessons were learned, mistakes made, and continuous improvement would be advocated for future studies. Innovation has been achieved on the following levels:

- The researcher has assumed a new role in the form of the Farm Sustainability Manager for ASW responsible for evaluating on-farm practises and embedding sustainable practises into the ASW growing operation (Figure 41).

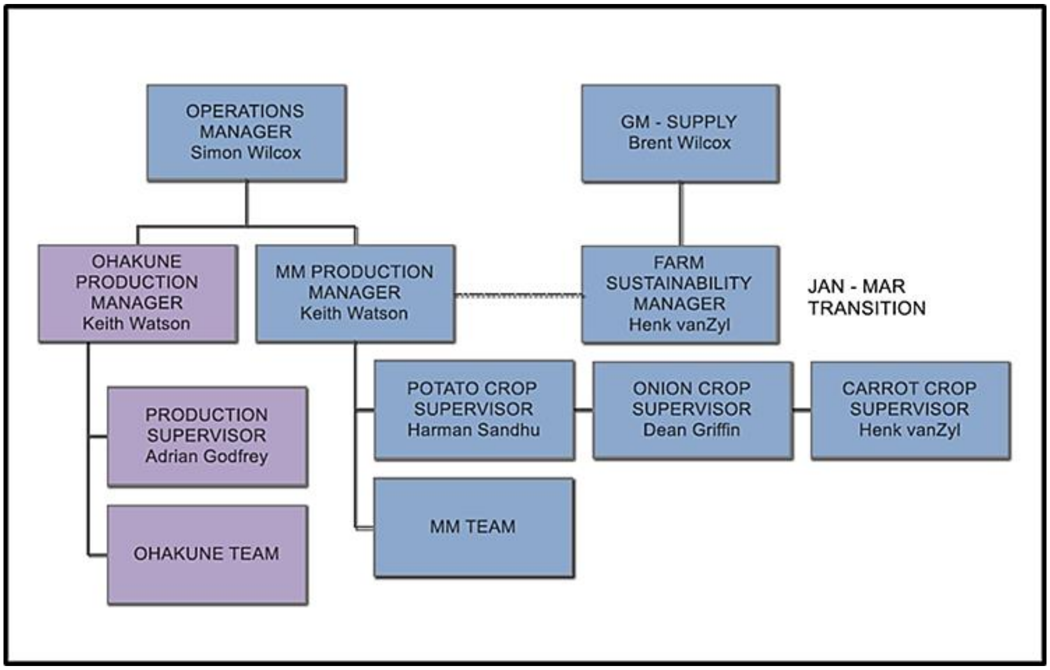


Figure 41: New organigram for the ASW Growing team.

- A practical and cost-effective method of fertigation has been adapted as a commercial practice within the Matamata production unit of ASW and 35 ha of commercial onions will be grown under this protocol in the 2018/2019 season.
- Compost has been produced with industry partners to the specified recipe and has been applied successfully.

5.5 Recommendations

- The need to work with industry partners to develop and supply liquid fertiliser is essential for the successful implementation of fertigation technology on a larger scale.

- Automatization of the fertigation system should be considered for implementing this practice.
- It is essential to develop and establish reference values and indicators of agricultural sustainability to determine the benchmark for implementation.
- Agro-chemical usage needs to be benchmarked and dust, chemical, and sediment pollution reduced.
- Cost effective compost with adequate microbial life attributes, produced to the desired specification, will have to be sourced or produced in-house.
- The company would benefit from improved community involvement with schools, community gardens and other projects in the Matamata region.
- Succession planning for the business and attracting young talent for ASW would be of importance.
- Developing a marketing message around sustainability and the ASW (Story) would be beneficial to the sustainability initiative. Gaining access to non- traditional markets (China), should be explored and expanding the current marketing model to include on-farm markets and retain the WILCOX brand name in the marketing arena would be beneficial.
- Continue doing trial work to prove sustainability concepts within the business.
- The company should be actively involved in influencing policy and should take note of the Waikato Regional Council's objectives within its clean river initiative.
- The business could take the initiative in developing a circular economic model.

5.6 Opportunities for Further Research

Further research on the implementation of eco-agricultural principles is critical to draw some conclusions and correct some errors in the implementation of eco-agricultural farming practices. Based on the results of the Qualitative and Quantitative research, opportunities for further research have been identified and are presented below.

- This study focused on the improvement of soil health as a low hanging fruit for implementing eco-agricultural practices. The principal of eco-agriculture encompasses much more than soil health and should be explored to its full extent.
- It became clear through the research that the microbiology in the soil was a critical component which had to be addressed. Alternative options to measure microbial activity should be pursued.
- There is an opportunity to investigate business models for successful implementation of eco-agricultural principles in the conversion of conventional farming systems into more sustainable systems, and this could be part of a future PhD study.

List of Appendixes

Appendix A: Participant Information Sheet

Researcher: Henk van Zyl

The purpose of this project is to introduce eco-agricultural principles to market gardening in the Waikato through collaboration, understanding, trans-disciplinary research and implementing innovation.

As part of this initiative, we are completing semi-structured interviews with stakeholders who are:

1. A.S. Wilcox employees.
2. Landowners in the region.
3. Service providers or industry partners.
4. Those involved in the regulatory environment.

You have been identified as an appropriate person to talk to and so we would like to interview you. This process should not take more than 30 minutes. The interview will be conducted at a place of your convenience. The interview will be recorded, and the transcription thereof will become part of a thesis that will be published. It is not compulsory to participate, and you may withdraw at any time.

If you choose so, you may remain anonymous. Your inputs will be referenced and acknowledged according to academic standards. A transcript of the interview will be available on request.

This project is funded by A.S. Wilcox and Sons Ltd.

It involves a large amount of collaboration between academic institutions, industry groups, researchers, policy agencies and service providers. This is best illustrated by listing those involved in the project reference team. They include:

• Wintec	• AgResearch
• FAR®	• Plant and Food
• Onions New Zealand	• Potatoes New Zealand
• Irrigation New Zealand	• Waikato Regional Council
• Matamata/Piako District Council	• John Austin Contractors
• Waterforce	• EM New Zealand
• Daltons™	• Fruitfed
• Balance	

As well as a range of other applicable providers.

This work aims to identify the relevance of sustainable farming and eco-agricultural principles for A.S. Wilcox in the Waikato.

Please forward any enquiries to henk.vanzyl@aswilcox.co.nz

Appendix B: Ethics Approval

Wintec
WAIKATO INSTITUTE OF TECHNOLOGY

Waikato Institute of Technology
Research and Postgraduate Office
D Block, Tristram Street / Private Bag 3036
Hamilton 3240
e-mail research@wintec.ac.nz
Telephone 07 834 8800 Extn 3582

13 March 2019

Centre for Research and Applied Innovation
Henk van Zyl

Dear Henk,

LOW-RISK HUMAN ETHICS RESEARCH APPLICATION

Title: A transdisciplinary approach to implementing eco-agricultural principles in the Waikato

Thank you for your low-risk application which was considered by the Chairperson of the Human Ethics in Research Group on 13 March 2019. I am pleased to inform you that low risk ethics approval has been granted.

Ethical approval is granted to 31 December 2019 or until the project has been completed, whichever comes first.

The Chairperson and the Human Ethics Research Group wish you every success with this project.

Kind regards

Megan Allardice
pp Elizabeth Bang
Chairperson
Wintec Human Ethics in Research Group.

C.c. Henk Roodt, Supervisor.

Appendix C: Summary of Interview Discussion Themes

Researcher: Henk van Zyl

The purpose of this project is to introduce eco-agricultural principles to market gardening in the Waikato through collaboration, understanding, trans-disciplinary research and implementing innovation.

Discussion points:

1. Identifying the interviewee
2. Determining his/hers/it's relationship and relevance to the research project.
3. Connecting a time frame to the relationship.
4. Gaining an understanding of your perception of the term "Sustainability"
5. Doing a SWOT analysis regarding the company, department or person regarding a sustainability initiative.

SWOT Analysis is a useful technique for understanding your Strengths and Weaknesses, and for identifying both the Opportunities open to you and the Threats you face. Used in a business context, it helps you to carve a sustainable niche in your market.(Retrieved from: https://www.mindtools.com/pages/article/newTMC_05.htm, 2019).

6. General comments and remarks around the topic of sustainability for ASW.

Appendix D: Participant Consent Form

Waikato Institute of Technology
Tristram Street, Private Bag 3036
Waikato Mail Centre
Hamilton 3240, New Zealand

Telephone +64 7 834 8800
Free phone 0800 2 Wintec (0800 2 946 832)
www.wintec.ac.nz

Project Title

A trans-disciplinary approach to implementing eco-agricultural principals in the Waikato

Participant Consent Form
(One copy to be retained by the Research Participant and one copy to be retained by Researcher)

I…………………………… (Participant's name) consent to be a participant in the above-named research project, and I attest to the following:

1. I have been informed fully of the purpose and aims of this project
2. I understand the nature of my participation
3. I understand the benefits that may be derived from this project
4. I understand that I may review my contributions at any time without penalty
5. I understand that I will be treated respectfully, fairly and honestly by the researcher/s, and I agree to treat the other participants in the same way
6. I understand that I will be offered the opportunity to debrief during, or at the conclusion of this project
7. I have been informed of any potential harmful consequences to me of taking part in this project
8. I understand that I may withdraw from the project at any time (without any penalties)
9. I understand that my anonymity and privacy are guaranteed, except where I consent to waive them
10. I understand that information gathered from me will be treated confidentially, except where I consent to waive confidentiality
11. I agree to maintain the anonymity and privacy of other participants, and the confidentiality of the information they contribute.

Participant………………………………………………………………Date……………

Principal Researcher…………………………………………………………… Date……………

Appendix E: Soil Report

Manaaki Whenua
Landcare Research

SOIL REPORT

Environment Waikato

Report generated: 20-Feb-2019 from https://smap.landcareresearch.co.nz

This information sheet describes the typical average properties of the specified soil to a depth of 1 metre, and should not be the primary source of data when making land use decisions on individual farms and paddocks.

S-map correlates soils across New Zealand. Both the old soil name and the new correlated (soil family) name are listed below.

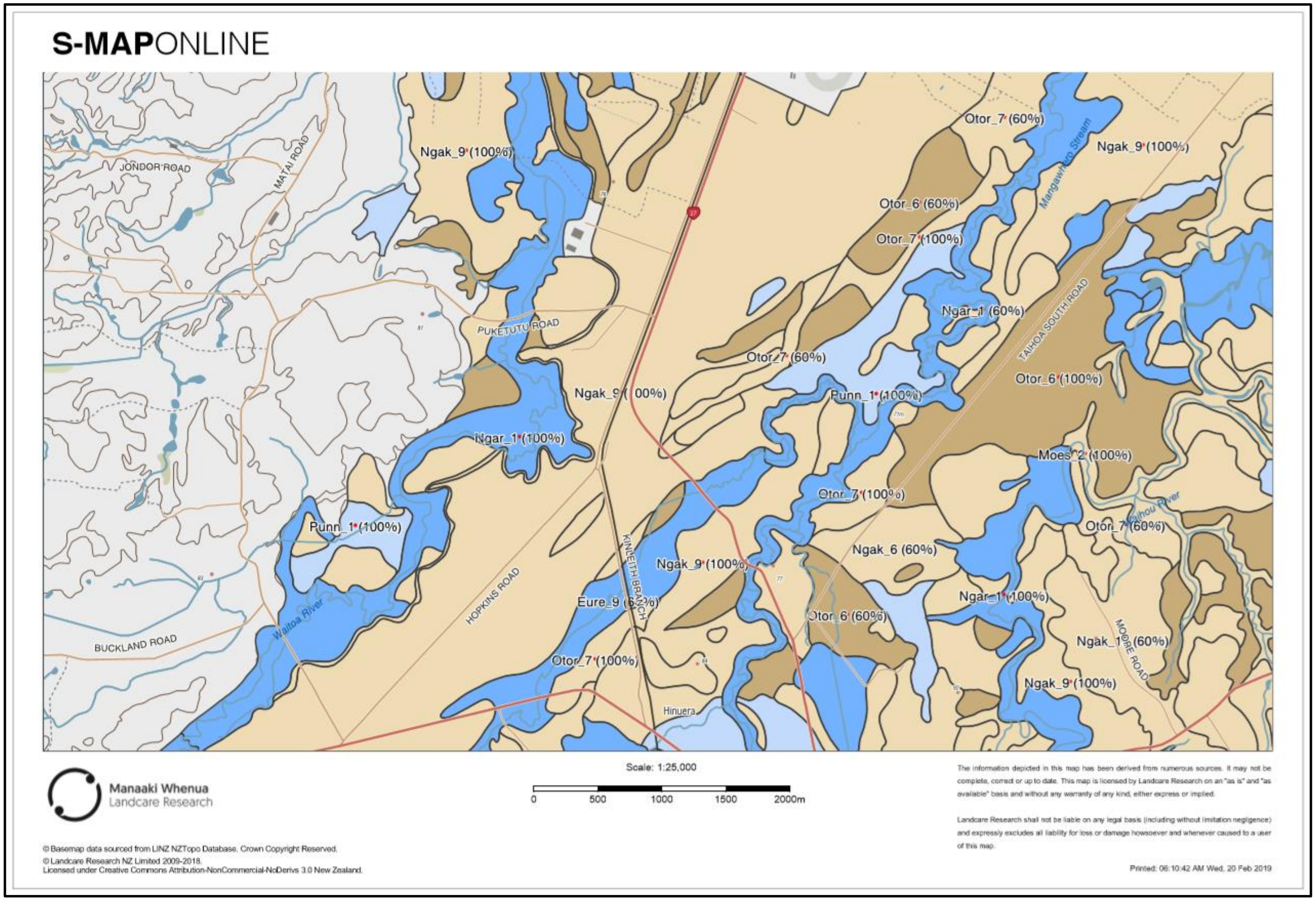
Family: Ngakura*f* | **Smap ref:** Ngak_9a.1

Waihou silt loam (Ngakura_9a.1)

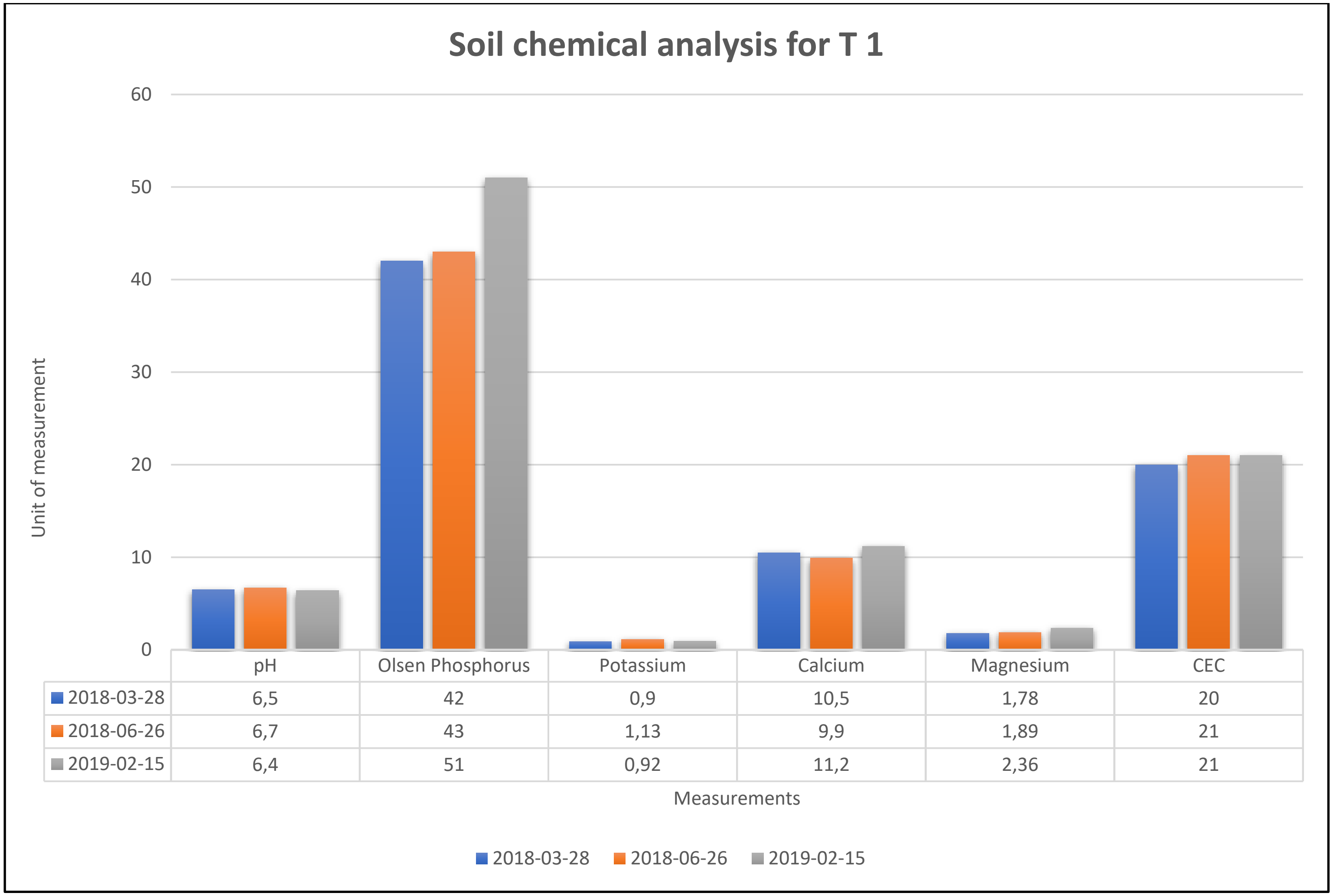
Key physical properties

Depth class (diggability)		Deep (> 1 m)
Texture profile		Loam over sandy loam
Potential rooting depth		Unlimited
Rooting barrier		No significant barrier within 1 m
Topsoil stoniness		Stoneless
Topsoil clay range		20 - 25 %
Drainage class		Well drained
Aeration in root zone		Unlimited
Permeability profile		Rapid
Depth to slowly permeable horizon		No slowly permeable horizon
Permeability of slowest horizon		Rapid (> 72 mm/h)
Profile available water	(0 - 100cm or root barrier)	High (226 mm)
	(0 - 60cm or root barrier)	Very high (145 mm)
	(0 - 30cm or root barrier)	High (73 mm)
Dry bulk density, topsoil		0.78 g/cm³
Dry bulk density, subsoil		0.86 g/cm³
Depth to hard rock		No hard rock within 1 m
Depth to soft rock		No soft rock within 1 m
Depth to stony layer class		No significant stony layer within 1 m

Appendix F: Matamata Soil Maps

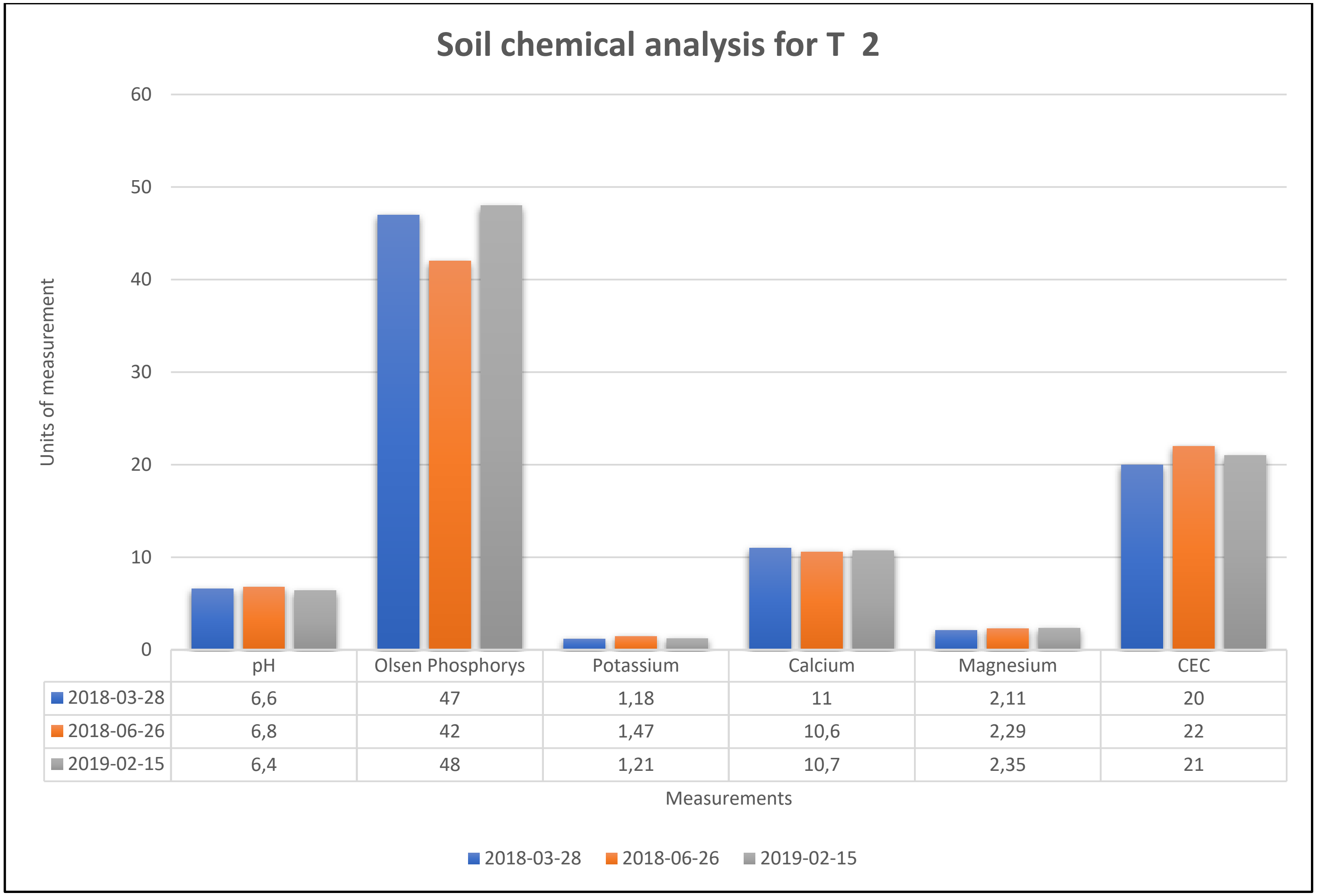


Appendix G: Soil Chemical Analysis for T 1



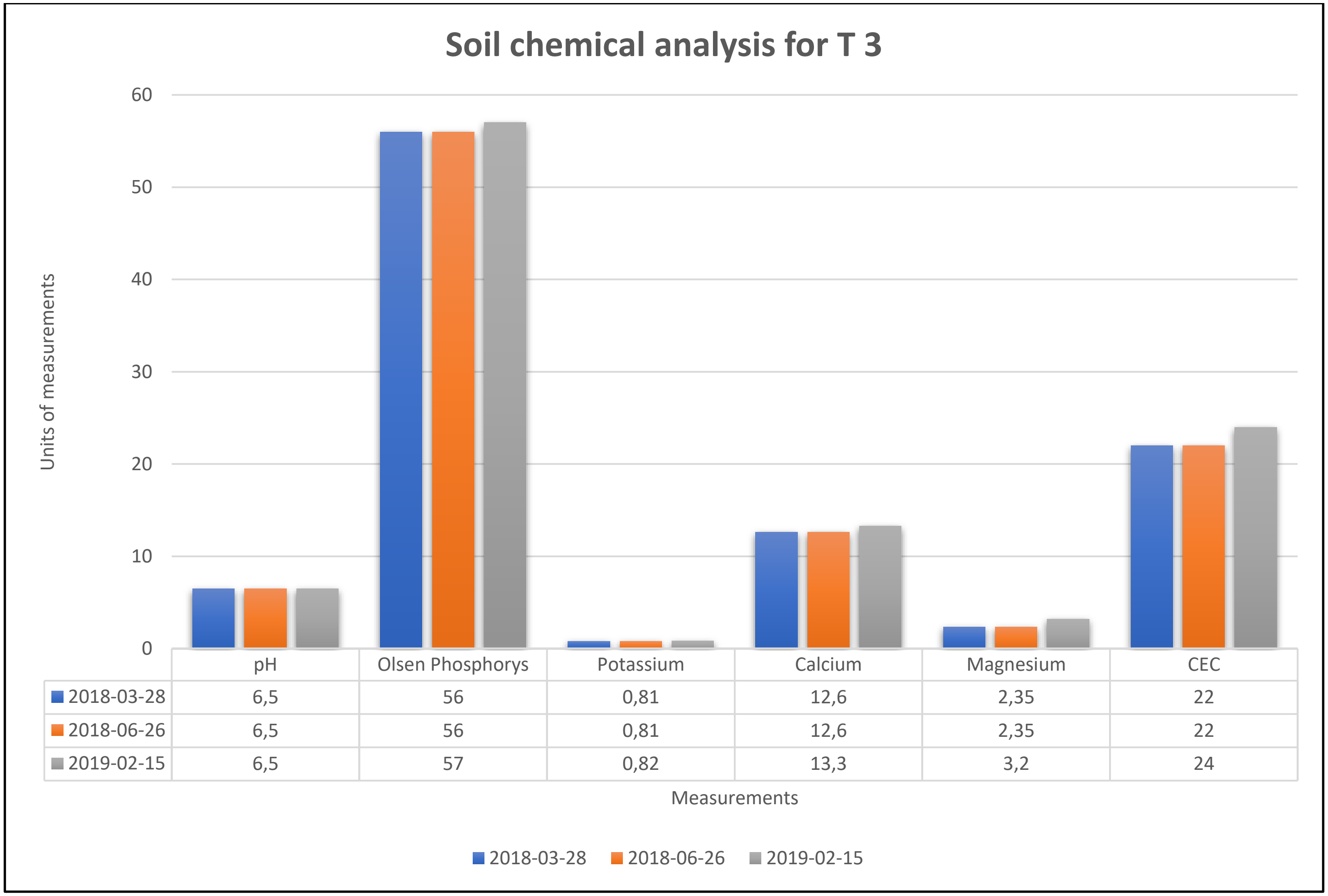
	pH	Olsen Phosphorus	Potassium	Calcium	Magnesium	CEC
2018-03-28	6,5	42	0,9	10,5	1,78	20
2018-06-26	6,7	43	1,13	9,9	1,89	21
2019-02-15	6,4	51	0,92	11,2	2,36	21

Appendix H: Soil Chemical Analysis for T 2

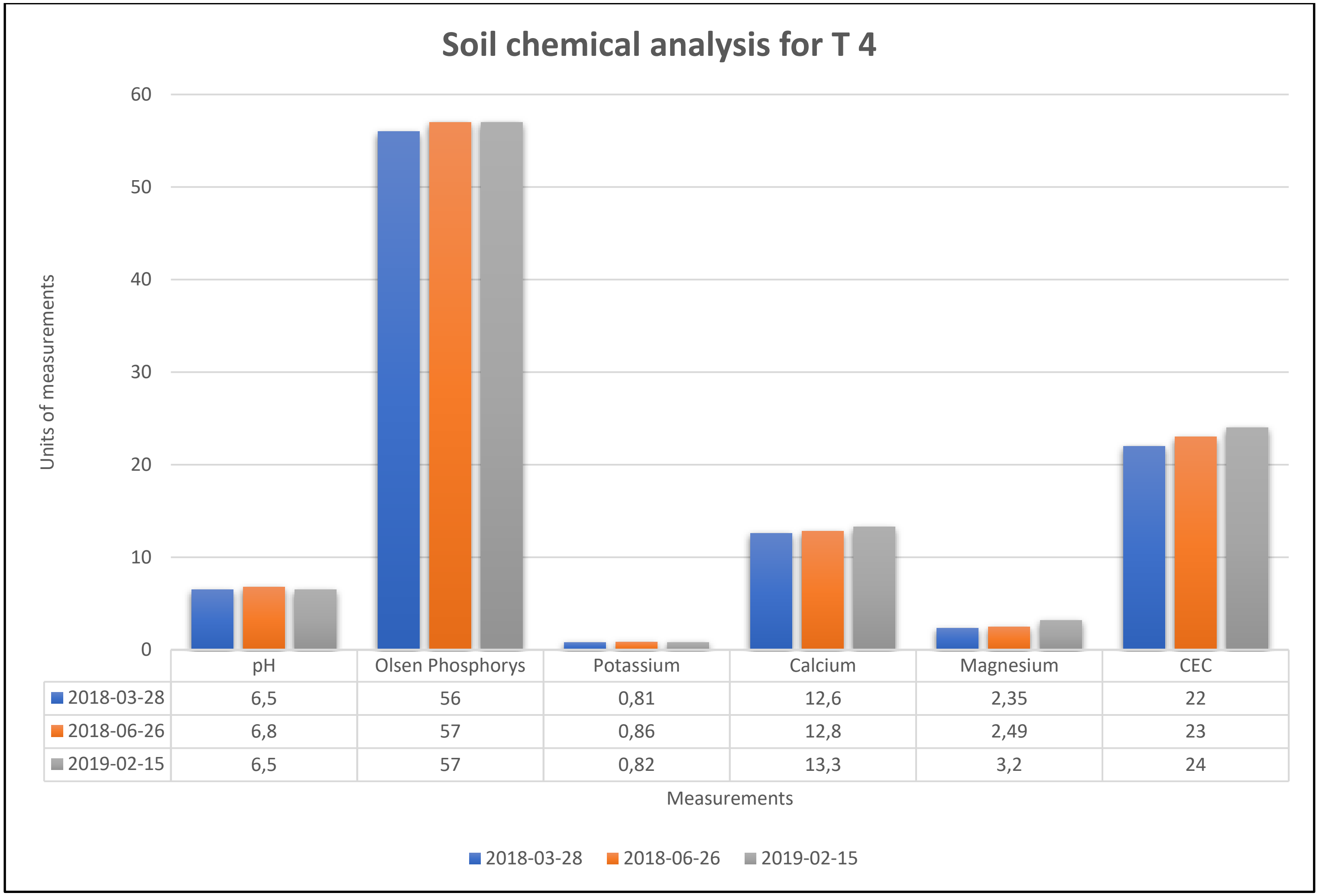


	pH	Olsen Phosphorys	Potassium	Calcium	Magnesium	CEC
2018-03-28	6,6	47	1,18	11	2,11	20
2018-06-26	6,8	42	1,47	10,6	2,29	22
2019-02-15	6,4	48	1,21	10,7	2,35	21

Appendix I: Soil Chemical Analysis for T 3

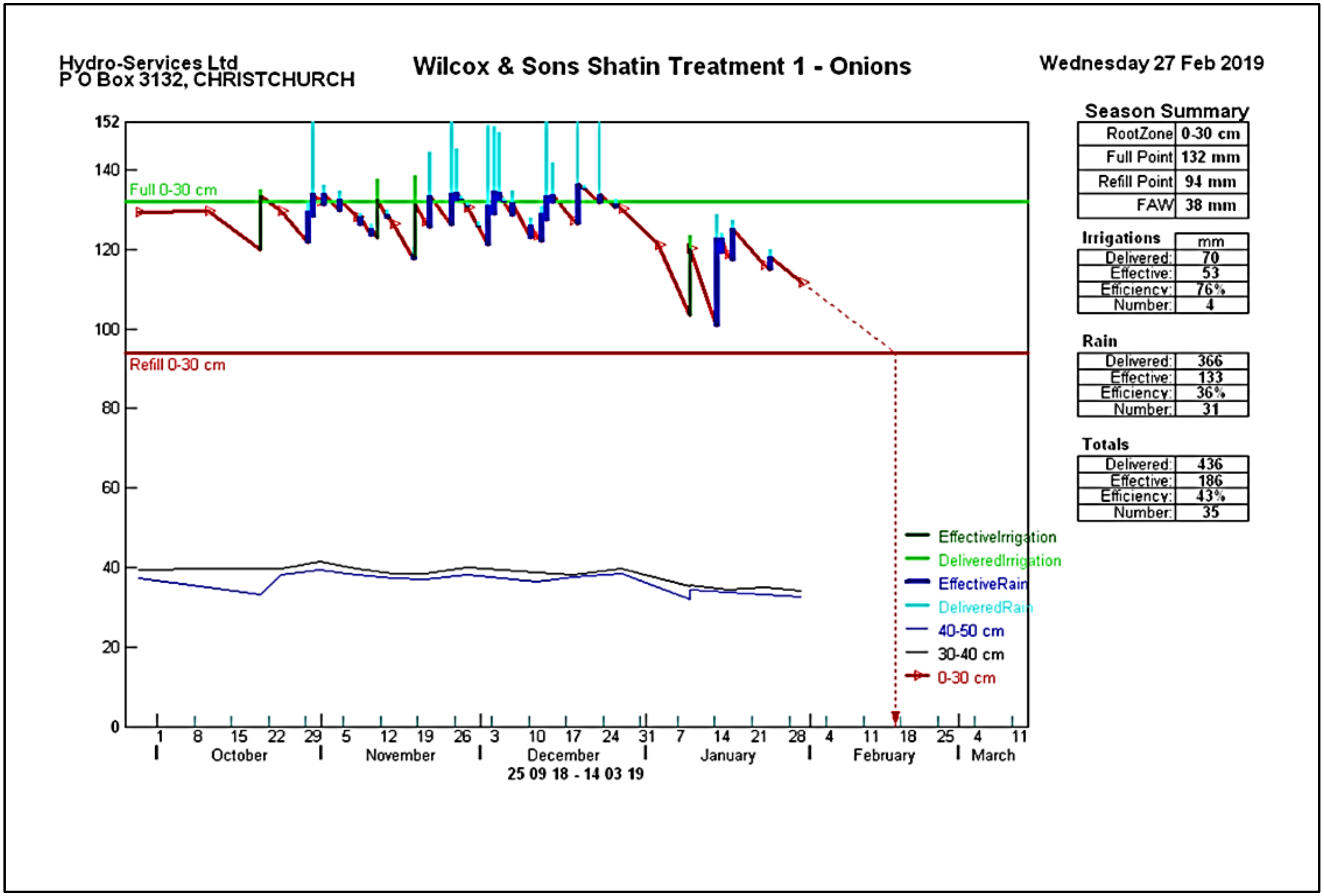


Appendix J: Soil Chemical Analysis for T 4

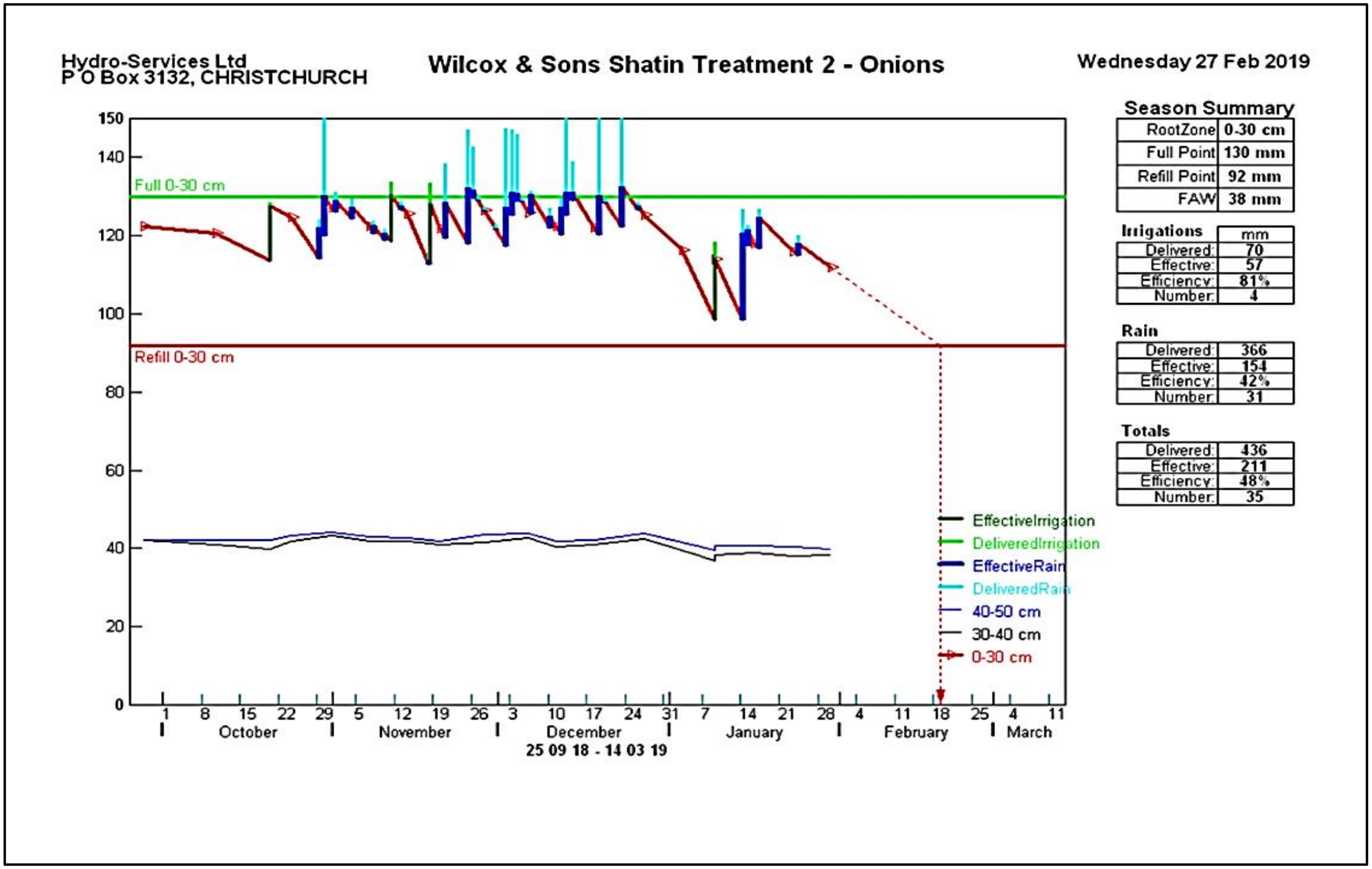


	pH	Olsen Phosphorys	Potassium	Calcium	Magnesium	CEC
2018-03-28	6,5	56	0,81	12,6	2,35	22
2018-06-26	6,8	57	0,86	12,8	2,49	23
2019-02-15	6,5	57	0,82	13,3	3,2	24

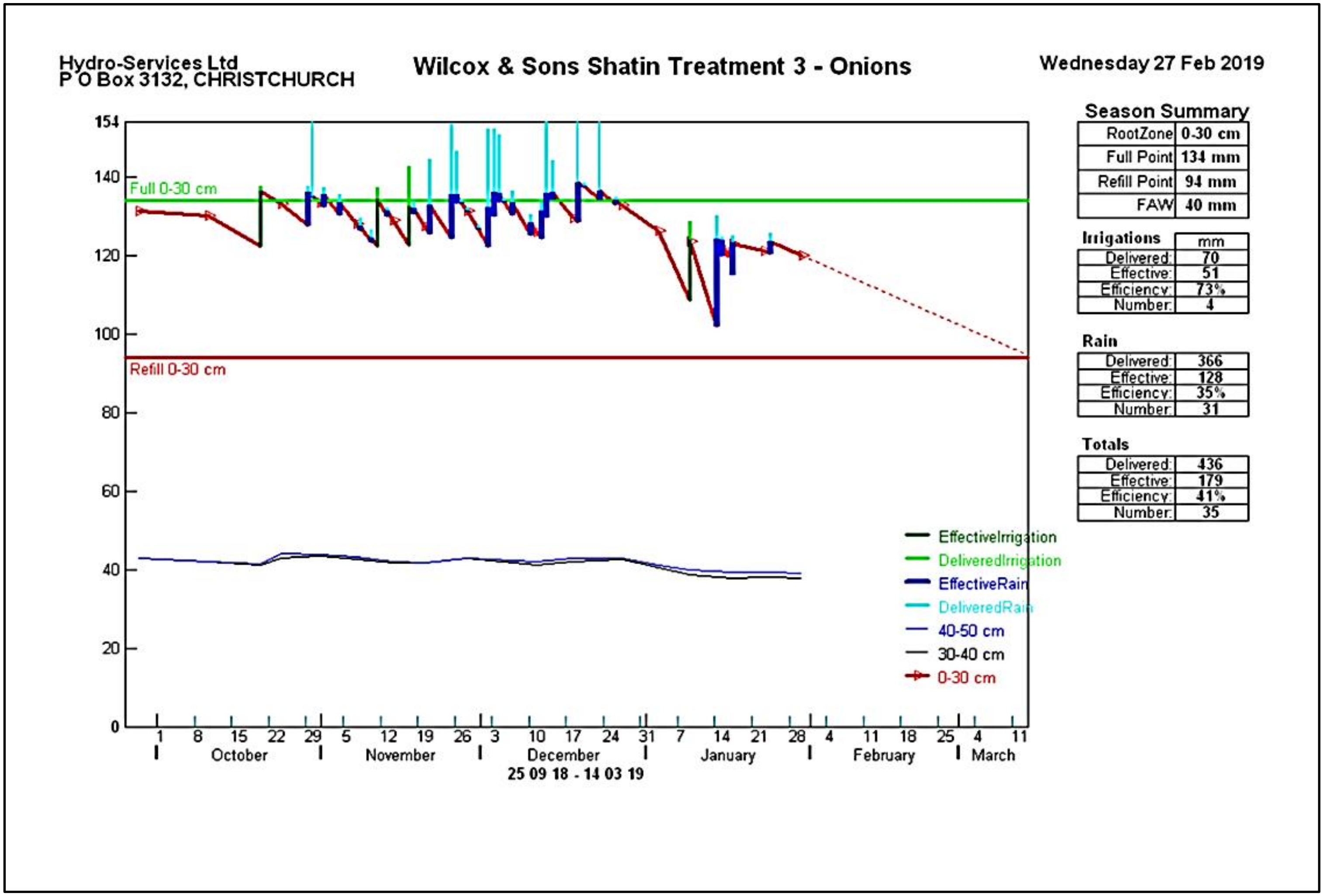
Appendix K: Soil Moisture Report for T 1



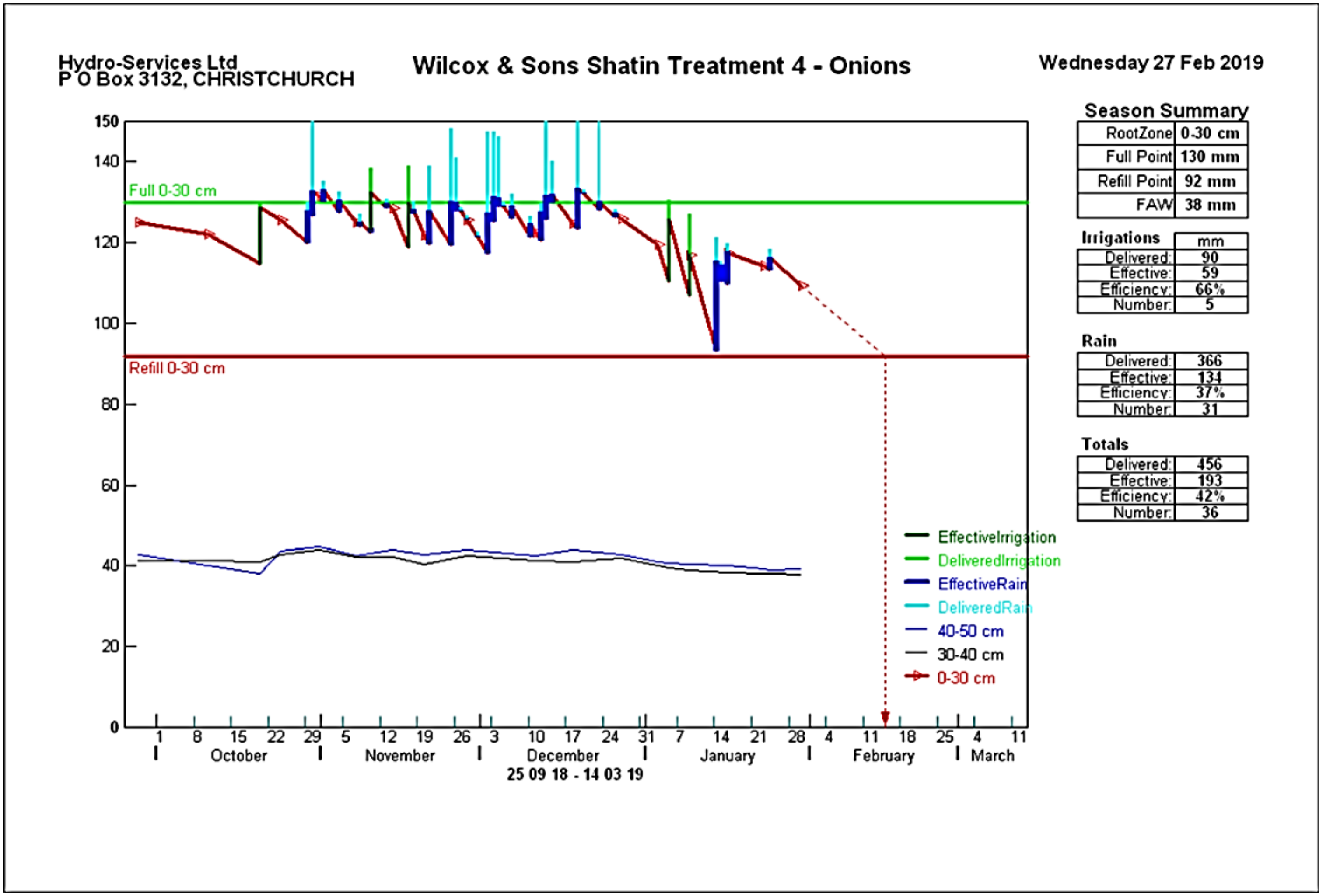
Appendix L: Soil Moisture Report for T 2



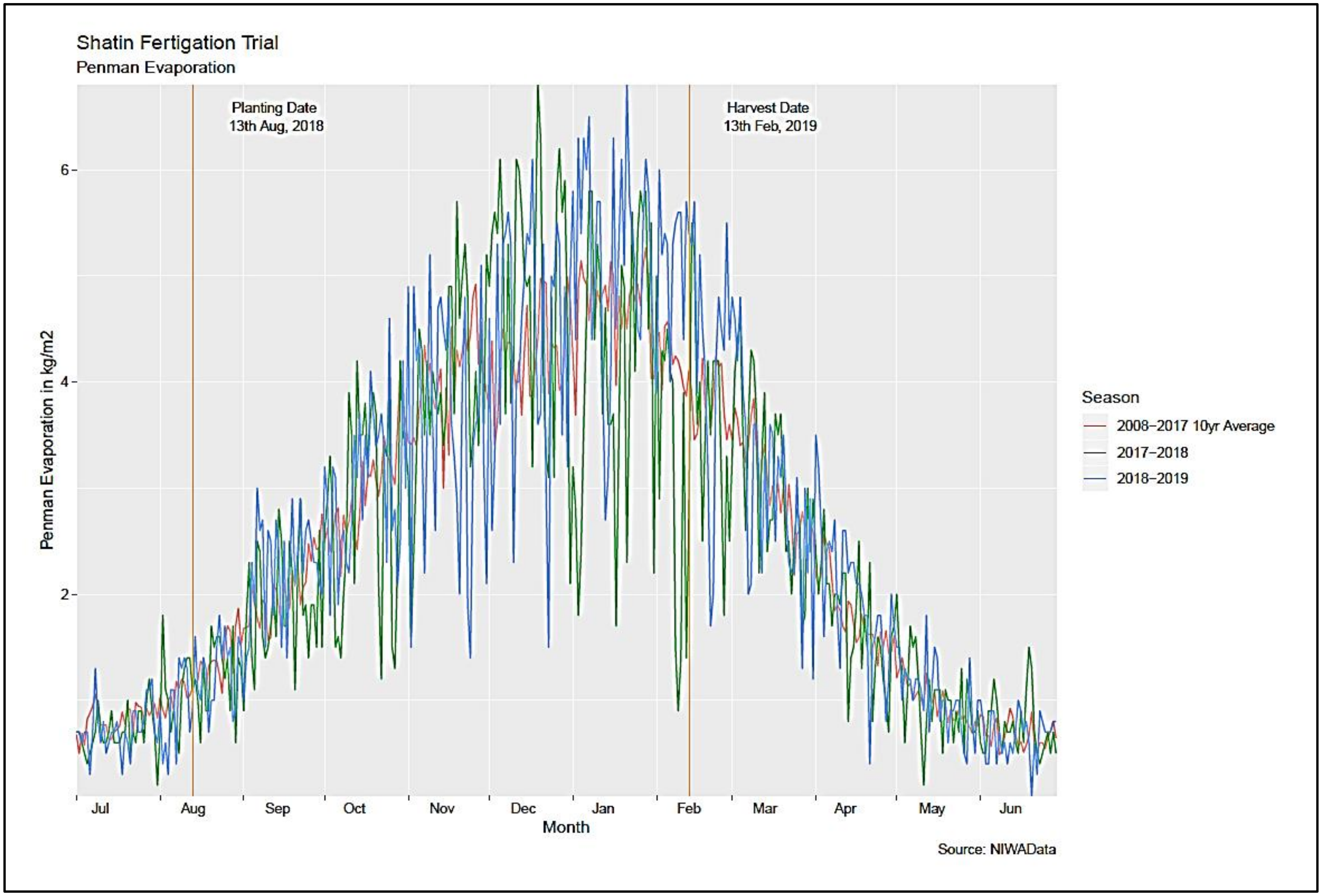
Appendix M: Soil Moisture Report for T 3



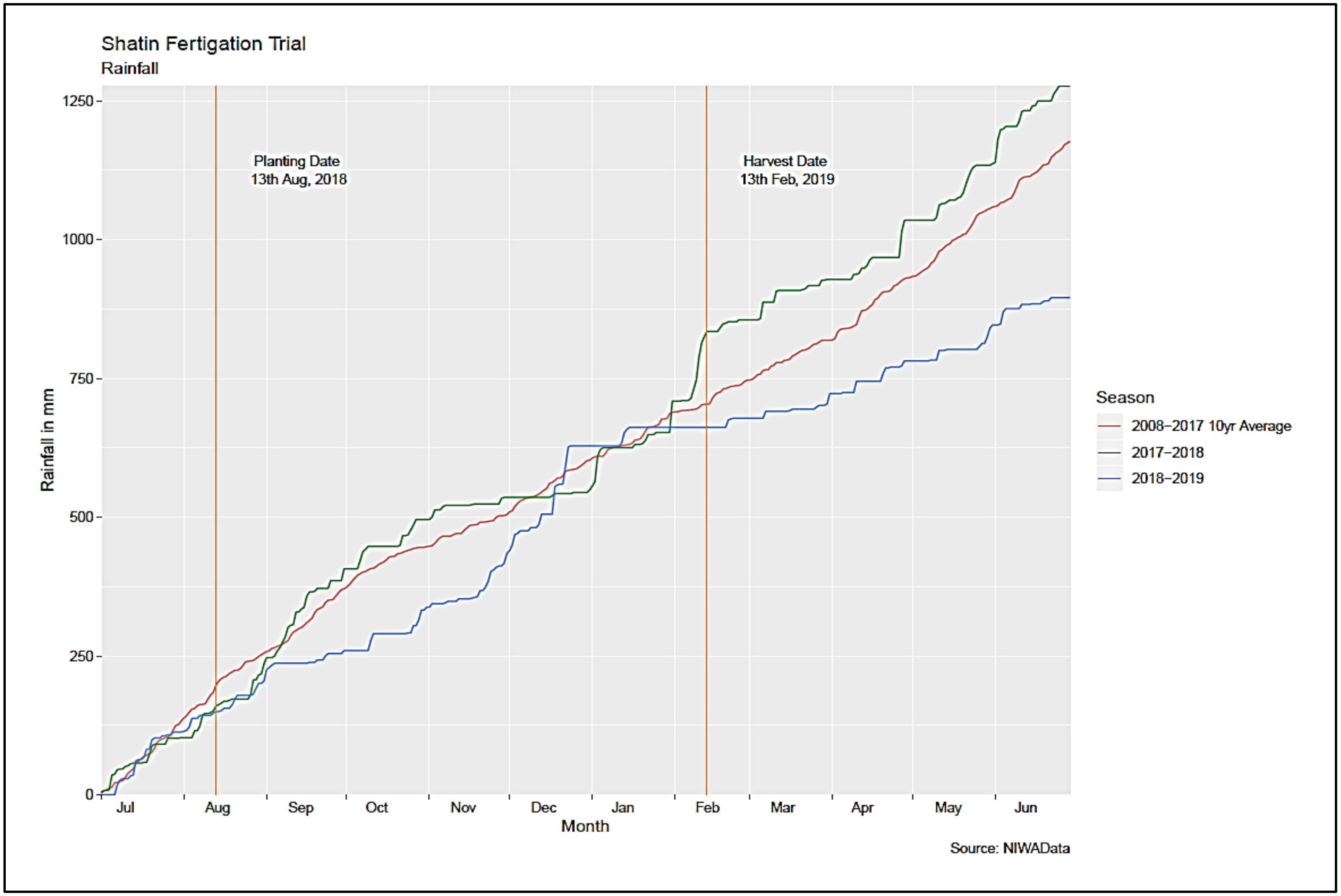
Appendix N: Soil Moisture Report for T 4



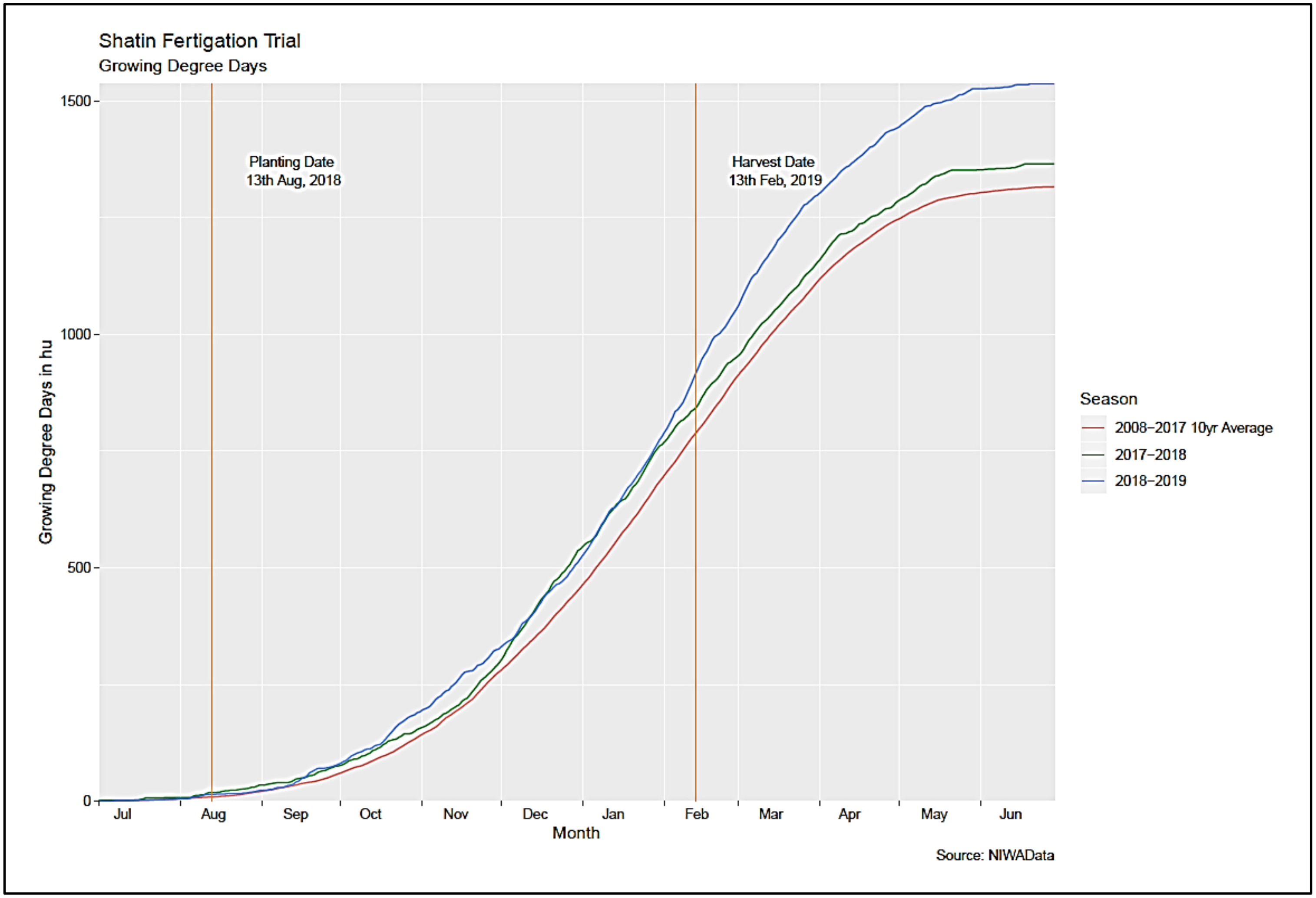
Appendix O: Evaporation



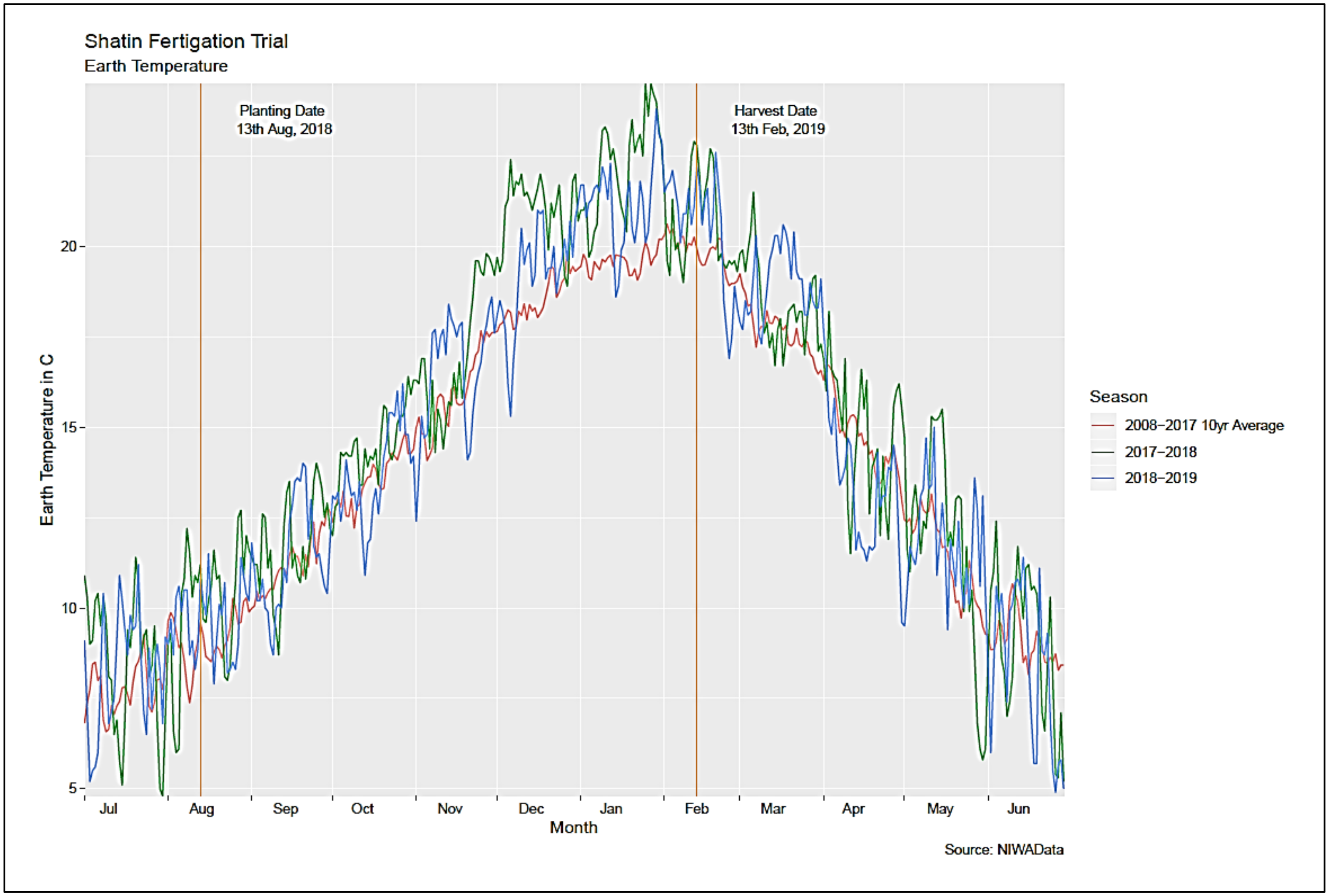
Appendix P: Rainfall



Appendix Q: Degree Days



Appendix R: Temperature



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